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High Voltage Direct Current Transmission

By R. I. STOCKLAND, U.S. Department of Commerce. (From *FIAT Final Report*, No. 904, June, 1947, 248 pages, 48 illustrations.)

RESEARCH and development on high voltage transmission in Germany was carried out in anticipation of the conquest of the whole of Europe by Germany, and rough plans were made for the creation of a European high voltage grid, for the operation of which the Norwegian water power resources were to play an important part. Electricity was to be carried from Scandinavia to the Continent by underwater cables and pooled with the water power resources of the Massif Central of France, and the Danube at the Iron Gate in Roumania, and supplemented by power from Switzerland, Italy and other countries, including Great Britain.

In addition to the technical and economic advantages expected from this system, the following secondary considerations were also taken into account, especially because the transmission would allow the use of underground cables for big loads : cables (1) are safe from atmospheric disturbances ; (2) can be laid where there is little convenient space, e.g. in mountains, built-up areas, etc. ; (3) are safe from direct air attack ; (4) do not spoil the landscape ; and (5) do not interfere with air traffic and telephone circuits.

A " High Voltage D.C. Transmission Board " was set up and large scale experiments were carried out at Hallendorf and over the following distances : Lehrte—Miesburg (Marx system), Charlottenburg—Moabit (Siemens Schuckert system), Zürich—Baden (Brown Boveri system), Vockerode (Elbekraftwerk) — Berlin-Mariendorf (A.E.G. and Siemens Schukert) ; the latter covered the longest distance (70 miles), was designed for an ultimate transmission of 120 MW at 400 kV, and was the most important of these experimental plants. It was nearly completed at the time of the German collapse.

The overall direction of the Elbe Power Station to Berlin project was vested in the Elektrowerke A.G. and it was arranged that the + 200 kV system would be developed by Siemens Schuckertwerke A.G., and the —200 kV system by the A.E.G. Transmission was to be by two 200 kV underground cables with a ground neutral.

The report under review describes progress made in Germany in the field of high voltage d.c. transmission and contains many technical and other details, including translations of original German papers. It also gives a comprehensive bibliography on the subject. The following is a short abstract condensed from pp. 13-26 of this report.

FUNDAMENTAL CIRCUIT OF THE ELBE POWER STATION TO BERLIN TRANSMISSION PLANT.

The transmission load for the initial construction was $2 \times 30 = 60$ MW, the d.c. voltage 2×200 kV. A.E.G. and S.S.W. would each build half of the system.

The d.c. transmission line forms a link between the 110 kV bus of the Elbe power station and the 30 kV bus of BEWAG* in Berlin over a distance of about 120 km. The two networks, which were to be connected, operated in synchronism at times, since in addition to the d.c. line there was an older a.c. link. But since the generators of the Elbe power house, which feed the d c. line, could also operate separately, asynchronous operation of the two a.c. networks had to be taken into account also for the d.c. transmission. This had no bearing on the construction of the main apparatus, but it did influence, e.g. the choice and design of load regulation.

The a.c. current was to be converted to a suitable voltage by means of single-phase transformers and rectified to 200 kV d.c. by means of single anode mutators (Fig. 1). Both halves of each plant in each station, each 30 MW, were to be connected in series so that + 200 kV d.c. would be produced by one half and —200 kV d.c. by the other. The neutral was to be grounded. Each half was to be operable by itself, in which case the return current would flow through the ground. In addition it was provided that both halves should work with different transformer connections to provide a greater number of phases for rectifier operation and reduce the reaction of the rectifiers on the a.c. network.

The 3-phase bridge circuit was chosen for the mutator units. At the same time, on account of the high d.c. voltage required, a series connexion of three tubes was provided, which also would provide much better security against backfires.

*Berlin Power & Light Co.

Two reactors of relatively high inductance were provided in each station in series with the d.c. lines (one each in the plus and minus conductors). Here also the test operation was to show whether small smoothing reactors could be used. By separation into a number of units the value of inductance could be varied enough for research purposes, to determine the optimum conditions.

In addition to the two d.c. cables, each about 120 km long, which were initially designed for a current strength corresponding to the final development, a control cable was to be laid in the same cable trench, to handle communications, remote control and remote measuring. This cable would also provide for the simultaneous protection of both stations.

The receiving station was very similar to the sending station in its construction. The only essential differences were due to the different a.c voltage.

The transmission was considered first of all for energy transfer from Elbe to Marienfeld. But it was considered that energy was sometimes supplied from Marienfeld to Elbe and this could be done by switching at no load. The automatic load regulation was initially projected only for energy transfer from Elbe to Marien-

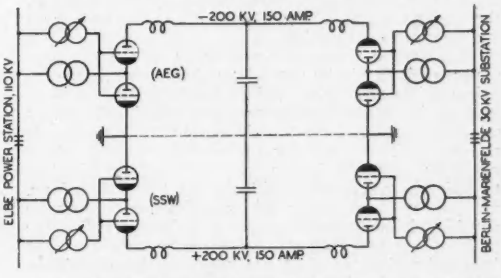


Fig. 1. Basic circuit of Elbe-Berlin high voltage direct current transmission.

feld. In case the energy flowed in the other direction, the load would have to be regulated by hand.

Insulating transformers were used because control and excitation energy and current for other applications were to be supplied to mutator tubes standing at a high potential. The A.E.G. plant was so arranged that the auxiliary circuits were first brought to a medium voltage of 100 kV by means of a common insulating transformer from which they were raised to the tube potential of over 200 kV maximum by means of smaller insulating transformers provided for each separate mutator.

A condenser was connected in parallel with each single anode mutator to divide the voltage equally among the three tubes connected in series.

Load switching in the high voltage d.c. circuit was omitted in the first construction. But at the start the necessary arrangements were made so that a d.c. circuit breaker could be provided and tested. Although d.c. circuit breakers are not needed for simple transmission between two stations, as in the Elbe-Berlin case where all switching can be undertaken on the a.c. side or with the aid of the grid control, the circuit breaker question becomes serious if one or several branches on the d.c. side or a d.c. network is to be reckoned with. In that case operation of a constant voltage d.c. transmission system without d.c. current breakers is no longer practicable. On the solution of the circuit breaker question depends the choice of retaining a constant voltage system, such as is used in the usual a.c. transmission, or turning to a constant current system.

In the overall layout the possibility of producing, on the spot, the reactive power needed in the inverter station was considered. Furnishing the reactive power from the BEWAG network would certainly have been difficult, even for the initial load of 2×30 MW. If the d.c. transmission load were raised to 2×60 MW, it would be almost impossible with the existing construction and operation of the BEWAG network. It was therefore intended from the first to install synchronous or static condensers, and the possibility of suitable regulation was studied.

Arrangements were also made to remove possible high frequency disturbances that can result from normal or disturbed operation of the high voltage mutators. For this purpose high frequency reactors or filters were to be connected to the a.c. lines in both stations and these were designed according to experience on similar equipments. Their chief purpose was to eliminate possible interference with telephone circuits along the line.

The cooling medium for the A.E.G. mutators was to be Clophen, which was to be circulated through insulator pipes to the cooling jackets of the tubes. As the insulator sections were long enough (about two meters) to produce only a small voltage gradient, it can be assumed that no difficulties would result from using Clophen in reference to d.c. stresses. Clophen was used instead of another cooling medium (e.g. oil) because it is non-inflammable. If unexpected electrical troubles should arise, oil could easily be substituted as the cooling agent. The Clophen was to be water-cooled in normal recoolers.

Concerning the supply of energy to the auxiliary apparatus it should be noted here that the auxiliary circuits can be energized as desired from the 6 kV auxiliary bus of the power station or from the 6 kV tertiary windings of the main transformers. An exception is the a.c. grid voltage for the mutator tubes, which normally is supplied only from the tertiary winding, to maintain synchronism with the 110 kV or 30 kV a.c. network voltages under all conditions. It must be considered, of course, that the 6 kV and 110 kV (or 30 kV) busses of both stations are not always operated in synchronism as they are supplied from different generators. In this case the general auxiliary circuits are energized from the separate 6 kV auxiliary bus and cannot be transferred to the 6 kV tertiary winding of the main transformer. If the main and auxiliary busses are synchronized, a transfer can be made with proper transformer connexions, so that not only the a.c. grid voltage for the mutator tubes, but all auxiliary circuits, are fed from the tertiary winding of the main transformer.

MAIN TRANSFORMER.

(a) ELBE STATION.

For the Elbe mutator station seven single-phase transformers in all were supplied, three for the A.E.G. half, three for the Siemens half, and one to serve as a spare for both halves of the station. Each transformer contained a tertiary winding in addition to the two main windings. The technical data are as follows :

Load. Each single-phase transformer was rated at 12 MVA. For this rating normal loading with sinusoidal a.c. was presumed and it was assumed that the tertiary winding was unloaded. The latter was designed for a third of the rated load (i.e. 4000 kVA) for stability reasons. The power consumed by the auxiliary circuits is only a few hundred kVA.

Transformer Ratio between Primary and Secondary Windings. Depending on the transformer connexions the normal ratio between primary and secondary windings was 118/98 kV or 68/98 kV.

Rated Secondary Current. 122·5 amp.

Transformer Ratio between Primary and Tertiary Windings. 118/6 kV and 68/6 kV, respectively.

Connexion Possibilities and Taps in the Primary Winding. The main transformers were designed to be connected either delta or star on the primary side. If the three transformers for one half of a station were delta connected, the three for the other half were star-connected to obtain the conditions of a 12-phase connexion with regard to reactions on the a.c. network, which are much more favourable than in case of similar connexion of both transformer groups. The secondaries were always star-connected. The secondary voltage must be the same with the primaries connected delta or star, i.e. 98 kV phase and 170 kV line voltage. To change from primary-delta to primary-star connexions, the primary windings of each transformer must be arranged and resoldered to change the transformer ratio from 118/98 kV to 68/98 kV, as noted above.

The primary winding of each transformer was also equipped with taps to permit correlation with changing a.c. network conditions and to produce more favourable reactive power conditions for transmission. With the primaries delta-connected, corresponding to a primary voltage of 118 kV, the taps produced voltage changes of $\pm$ 2·5, $\pm$ 5, $\pm$ 7·5 and $\pm$ 10 per cent. With the primaries star-connected (producing 68 kV primary voltage) the corresponding values were $\pm$ 2·17, $\pm$ 4·34, $\pm$ 6·5 and $\pm$ 8·67 per cent.

Tertiary Winding Connexions. The tertiary windings of three single-phase transformers were delta-connected. Their voltage was independent of the primary winding connexions —6 kV. Loading the tertiary winding reduces the load of the secondary winding correspondingly, as the total rated load of 12 MVA must not be exceeded. The tertiary windings permit the flow of compensating currents in case they result from unfavourable network conditions or mutator operation. They also energize the auxiliary circuits of the respective station at times, but this needs only a very small amount of power.

Short Circuit Voltage. The short circuit voltage between the primary and secondary windings was 11·45 per cent. The short circuit voltage between the primary and tertiary windings was smaller, about 6 per cent. The ohmic resistance of this tertiary winding is 0·011 ohms.

Losses. They amounted to 72 kW copper losses per transformer (with an unloaded tertiary winding) and 65 kW no-load losses.

Cooling. The transformers were forced-air-oil-cooled.

Transformer Protection. Only a Buchholz relay and temperature protection was provided for the transformers. The forced air cooling of the transformer is cut in automatically when the load exceeds the permissible value for self-cooling (about one third of the rated load).

(b) MARIENFELD STATION.

There were seven transformers at Marienfeld station which differ from those for Elbe in the following details.

Transformer Ratio between Primary and Secondary Windings. Depending on connexions, the normal transformer ratio between the primary and secondary windings was 31·5/98 or 18·2/98 kV.

Transformer Ratio between Primary and Tertiary Windings. 31·5/6 or 18·2/6 kV.

Load Rating of Tertiary Winding. This was 30 per cent of the rated load, i.e. 3600 kVA.

Short Circuit Voltage. Between primary and secondary windings, 14 per cent ; between primary and tertiary windings, 1·17 per cent referred to the rating (3600 kVA) of the tertiary winding. This small value is due the to fact that in the A.C.E.C.* transformers for Marienfeld, the primary (30 kV) winding was between the secondary (98 kV) and tertiary (6 kV) windings. In the transformers for Elbe the secondary winding was between the primary (118 kV) and tertiary windings, so that in this case much higher leakage reactance was obtained between the primary and tertiary windings.

Losses. 72 kW copper losses and 41 kW no-load losses.

Smoothing Reactors. In all, four smoothing reactors (oil-self-cooled) were provided. Two reactors were allotted to Elbe Station and two to Marienfeld, where they were to be connected at times in both outer conductors of the line. Therefore, they were to operate continuously under high d.c. potential and were accordingly insulated for 220 kV.

The inductance of each reactor was four Henries at 150 amp. d.c. and a current ripple of 4 per cent.

Protection equipment, as for the transformers, consisted only of Buchholz relays and temperature protection.

Connexion and Arrangement of Mutator Tubes. As single anode tubes were used throughout, the three-phase bridge circuit (Graetz-circuit) was chosen, which basically requires six tubes, and, apart from the tube stresses and transformer utilization, produces the same conditions as the normal 6-phase connexion of rectifiers or inverters. Each tube was designed for an arithmetic mean value of 50 amp. and a r m.s. value of 86 amp., calculated from a transmission current of 150 amp., and a blocking voltage of 120 kV, at a line voltage of $98\sqrt{3} = 170$ kV. On the secondary side of the transformers the total voltage applied to the tubes during the blocked period is $170\sqrt{2} = 240$ kV. To withstand this voltage, therefore, at least two tubes must be connected in series.

By connecting several tubes in series and equalizing stresses on the several tubes, the security against backfires is markedly increased. The backfiring of tubes is a statistical probability and it is less probable that two tubes connected in series backfire simultaneously than that one backfires alone. Since backfires cause an inadmissible disturbance of the whole transmission, the stability of the Elbe-Berlin system was still further increased by connecting a third mutator tube in series. In all, for one half of the system in each station, i.e. to produce 200 kV d.c. to ground, $6 \times 3 = 18$ tubes were required. This so-called "safety circuit" operates so that the single tube is stressed at only $240/3 = 80$ kV, thus considerably under the permissible blocked voltage. The probability of backfires is thus reduced to a very important degree. But even if one of the three tubes connected in series should backfire, this does not mean a backfire of the whole series, as the two remaining tubes are not overstressed, so that it can be assumed that they will hold fast, at least for a short time. The cause for the backfire in the first tube is generally removed immediately so that the tube is again ready for operation in one of the following half waves and the normal operation of the three tubes in the series circuit is resumed automatically. The safety circuit can also be designed so that the third tube forms a standing reserve which can be cut in automatically if a tube should misfire. The interpretation is that it is better to increase somewhat the overall cost of the tubes and thereby increase the stability of transmission which would be disturbed by frequent backfires in especially disagreeable ways.

In the bridge circuit the anodes of three tubes are electrically connected to one d.c. conductor and the cathodes of three other tubes to the other d.c. conductor. The latter tubes bear the full d.c. voltage of $170\sqrt{2} = 240$ kV peak value. In order to avoid insulating all tubes for this high voltage, a division of voltage was provided and an intermediate voltage was was introduced. For this purpose the tubes are placed on a common base plate which is electrically connected to the neutral of the transformer secondaries. The peak value of the base potential is then $98\sqrt{2} = 140$ kV. The same voltage difference also exists between the tube at the highest potential and the base plate. In this way normal insulation for 110 kV a.c. is used to insulate the base plate from ground and the tubes from the base plate.

Not only the insulation of the tubes but also the insulation of the power leads to the auxiliary apparatus of the tubes is eased through introduction of the intermediate potential. Insulating transformers for 170 or 220 kV need not be provided, but 100 kV units are sufficient. With these transformers, as opposed to transformers for higher voltages, it is not difficult to provide a three-phase service to the auxiliary apparatus of the tube and to provide a separate circuit for the grid control.

Energy Supply to the Auxiliary Apparatus. As already stated it was possible to supply energy to the auxiliary apparatus in two ways—from the 6 kV auxiliary bus at the Elbe power station or the 6 kV line traversing the Marienfeld station, or from the tertiary windings of the main transformers. The basic arrangement is such that all auxiliary apparatus could be fed from either source but the possibility of energizing them partly from one source and partly from the other had also been foreseen. The latter method of operation is important in cutting the system into service.

For operating reasons two groups of auxiliaries must be distinguished :

1. The normal apparatus appearing in each station or on each mutator, as ignition, excitation, pump drives, etc , and
2. The devices for grid control, insofar as they require a special source of energy. Apparatus with which the a.c. grid voltage is produced and conducted to the tubes belongs in this group, while that required for the negative grid voltage is considered as group 1, apparatus.

In normal operation the auxiliary circuits of group 2 are fed from the tertiary windings of the main transformers. It would be possible to feed this equipment

*Ateliers de Construction Electriques, Charlevoi, Belgium.

also from the 6 kV auxiliary bus, if it is synchronized with the 110 kV or 30 kV main bus of the station. But in this case, under some conditions difficulties might result from inconstancy of the phase relations between the different voltages.

Grid Control and Regulation. For the grid control of the mutator tubes a so-called " impulse control " of special design was provided. The regulation results from displacement of a " governor " which is connected in the grid circuit of the control tubes, so that only a very small type is concerned. For hand regulation the so-called Toulon control is used, in which the a.c. grid voltage is displaced the desired amount from the anode voltage. This principle can also be used for the automatic regulation, if the " governor " is very small and its quick displacement therefore would involve no special difficulties ; but for automatic regulation a grid voltage control is used in which regulation results from changing the height of the negative grid voltage. With this method considerably higher-speed regulation is obtained than would be possible with the mechanical displacement of a grid governor. Thus, different regulation methods may be used at the same time to improve operation or its economy. The regulation provided for the Elbe-Berlin system not only affects the real power, but also reduces the reactive power to a minimum.

Voltage-dividing Condensers. The high voltage condensers, which were to be connected in parallel with each mutator tube to equalize the voltage across the three tubes in each series circuit, were designed for a capacitance of 0·011 μF each. They were insulated for the voltages occurring in normal operations and during disturbances. By disturbances is understood all operating conditions under which a tube backfires, so that then a peak voltage of 240/2 = 120 kV falls on each of the two good tubes in the affected series circuit and on the condensers connected in parallel with them. A small reactor of a few ohms was connected ahead of the condensers to reduce the equalizing currents at the moment of ignition and current interruption in the tubes.

The condensers were of the usual design for high voltage condensers for similar purposes. An exception was that Clophen was used instead of oil to reduce the fire hazard in the mutator room.

Insulating Transformers. Two types of insulating transformers were provided :

(a) A 200 kVA type to reach the potential of the mutator base plates ;

(b) A 10 kVA type to go from the base plate potential to the tube potential.

SWEDEN

The Semi-Inverted Diagram

By B. JAKOBSSON (From *Teknisk Tidskrift*, Vol. 77, No. 31, August 2, 1947, pp. 572–573 ; 5 illustrations.)

WHEN charting a diagram in a system of rectangular co-ordinates with linear scales, it is easy to choose convenient scales if the values are not greatly variable. In other cases it may be necessary to cover a wide range of variation by choosing a small scale, and by preparing one or more additional charts, on a larger scale, of particularly interesting ranges. Where wide numerical ranges are involved, a linear logarithmic or a log/log scale may be used. Unfortunately, however, logarithmic scales have the disadvantage that not only $x = \infty$ but also $x = 0$ is excluded from the diagram.

The proposed new type of chart makes use of the ordinary system of rectangular co-ordinates with linear co-ordinate scales, but covers the ranges $-\infty < x < \infty$ and $-\infty < y < \infty$. This enables the study of asymptotic characteristics to be carried out up to its limit.

The proposed new co-ordinate scales are shown in Fig. 1, where the infinitely long range of numerical

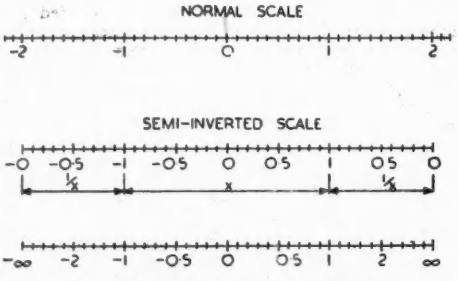


Fig. 1. **Normal and semi-inverted scale.**

values is covered by four unit lengths of gradation. In this way the $x-y$ system is reduced to a square, the sides of which represent four unit lengths of gradation,

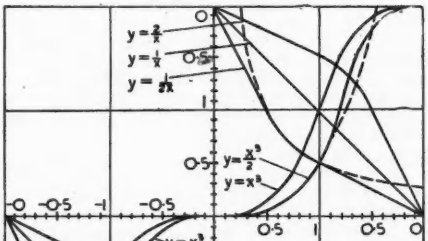


Fig. 2. **Typical semi-inverted diagram.**

The application of the method is illustrated in Fig. 2. The portion of the curves shown in broken line correspond to a linear scale. Hyperbolæ represent a special case, as they change into straight lines in certain inverted ranges. It is suggested that a diagram of this type should be called a " semi-inverted diagram."

At a first glance it would appear that curves should show a discontinuity of their first derivative at the transition from the linear to the inverted scale, but it can be proved mathematically that a continuous first derivative remains continuous in this mode of representation. Other derivatives and radii of curvature, however, become discontinuous.

Zicral—A New High-Tensile Light Alloy

By P. VACHET. (From *Revue de L'aluminium*, Vol. 24, Nos. 134 and 135, June-July and August, 1947, pp. 189-198, and 225-233, 17 illustrations.)

DURING the war, the French light-alloy industry developed a heat treated Al-Zn-Mg alloy, Zicral, which has an elastic limit of 28 to 38 tons per sq. in. (higher than that of Duralumin) and an elongation of 9 to 15 per cent.

I. THE DEVELOPMENT OF Al-Zn ALLOYS.

The possibility of obtaining heat treated high-tensile Al-Zn alloys was first shown in 1929. In 1935, systematic research was started and two groups of alloys were favoured for further investigations :—

(a) Alloys with less than 7 per cent Zn, 20 per cent elongation and a tensile strength approaching that of Duralumin. Development took place in Germany.

(b) " Zicral " alloys with 8 per cent Zn, about 32 tons per sq. in. tensile strength and a low elongation which can be improved by the addition of 2 per cent Mg. These alloys have been developed in France since 1939 and are now ready for industrial use.

TABLE I.—Mechanical properties of Al-Zn-Mg alloys. Tests made on extruded bars, heated for 4 hours at 450 deg. C., then quenched and precipitation heat-treated at 150 deg. C. for 6 hours.

Zinc Content	Magnesium Content. 1 per cent			2 per cent			3 per cent			4 per cent		
	E.L. kg/mm²	U.T.S. kg/mm²	El. %	E.L. kg/mm²	U.T.S. kg/mm²	El. %	E.L. kg/mm²	U.T.S. kg/mm²	El. %	E.L. kg/mm²	U.T.S. kg/mm²	El %
3 %	8·0	18·2	19·3	10·4	22·4	21·8	11·9	25·7	25·1	13·8	29·1	25·4
5 %	16·2	29·1	17·4	21·7	35·3	19·9	24·8	39·3	20·8	27·6	41·3	22·0
7 %	22·2	39·6	16·8	28·6	42·6	15·3	34·4	45·9	9·4	36·3	48·4	7·3
8 %	24·7	40·3	13·8	34·4	45·6	1·8	40·8	50·3	0·5	43·5	50·9	0·3
9 %	32·6	41·6	10·8	38·8	50·0	1·0	45·6	50·0	0·2	46·6	57·0	0

E.L. = Elastic limit ; U.T.S. = ultimate tensile stress ; El. = elongation ; 1 kg/mm² = 0·635 tons/in².

Table I shows the influence of zinc and magnesium additions on strength and ductility. Copper additions further increase tensile strength but progressively reduce ductility if present to more than 1 per cent. Chromium in very small quantities also increases strength and slightly reduces ductility. It greatly improves resistance against intercrystalline corrosion. Manganese should not be included to any appreciable degree because it affects the elongation, does not protect against corrosion, and raises the recrystallization temperature so that Zicral sheets cannot then be properly annealed at the quenching temperature and retain the structural irregularities of the hot-rolled material. A typical Zicral alloy thus contains 7 to 8·5 per cent Zn, 2·5 per cent Mg, 1·5 per cent Cu, 0·25 cent Cr, Al remainder.

II. CORROSION RESISTANCE OF ZICRAL.

A. HEAT TREATMENT AND CORROSION.

Age hardening at room temperature does not develop full elastic strength in Zicral and affects its corrosion resistance. A precipitation heat treatment is absolutely necessary. For corrosion tests, drawn Zicral rods, $^3/_{16}$ inch in diameter and 4 feet long were heated for 4 hours, water quenched and precipitation hardened in various ways. Of each treated batch, one bar was kept uncorroded, one placed axially on the periphery, and one bent elastically around the circumference, of a drum which was rotated over a bath of 3 per cent NaCl solution with inhibitor (A-3 reagent, French aeronautical standard). The rods were alternately immersed for one hour and dried in air for one hour. Some fractured spontaneously after several days, and in others, inter-crystalline corrosion increased the electric resistivity. Results (given in Table II) show that the alloy must not be quenched from too high a temperature nor precipitation hardened at or below 125 deg. C.

B. PROTECTION BY ANODIZING.

Anodizing in a sulphuric bath affords complete protection against corrosion and is recommended for rolled sections, forgings and unplated parts generally. Anodized Zicral may be left to age harden although full elastic strength cannot then be obtained (Table III).

TABLE II.—Increase, over the initial value, of electric resistivity of corroded bars. Values in microhms/cm.

Precipitation treatment	Corrosion without stress		Corrosion under tension	
	Quenched from 410 deg. C.	Quenched from 460 deg. C.	Quenched from 410 deg. C.	Quenched from 460 deg. C.
At 100 deg. C. 2 hrs.	0·11	1·51	fractured after 7 days	fractured after 1·5 days
At 100 deg. C. 5 hrs.	0·12	1·84	fractured after 7 days.	fractured after 3 days
At 100 deg. C. 10 hrs.	0·07	0·10	fractured after 19 days	fractured after 4 days
At 125 deg. C. 2 hrs.	0·08	0·11	fractured 14 days	fractured 6 days
At 125 deg. C. 5 hrs.	0·09	0·08	0·07	fractured 8 days
At 125 deg. C. 10 hrs.	0·07	0·13	0·07	0·10
At 150 deg. C. 2 hrs.	0·20	—	0·07	0·07
At 150 deg. C. 5 hrs.	0·11	0·07	0·06	0·07

C. PROTECTION BY PLATING.

Like Duralumin, Zicral can be protected by plating with a metal more electro-positive than the base metal. Electrode potential against standard calomel electrode in A-3 reagent is, for Dural 0·6 volts, pure Al 0·74, Al-Mg alloy 0·78 to 0·8, Zicral 0·8 to 0·85, 1 per cent Zn-Al alloy 0·88, 4 per cent Zn-Al alloy 0·96 volts. 4 per cent Zn-Al plating alloy seems most suitable and this was confirmed by practical plating tests which show that the protecting influence persists when the plating is partly removed. Even plated Zicral must not be age-hardened but should be precipitation heat treated for several hours at temperatures not below 125 deg. C. (Table III). Higher Zn-Al plating alloys show no additional improvement.

TABLE III.—Corrosion resistance of anodized and of 4 per cent Zn-Al plated Zicral after 6 months in saline vapour chamber.

Treatment		Anodized material: 0·15% Fe, 0·09% Si, 1·51% Cu, 7·17% Zn, 2·78% Mg, 0·25% Cr.									Plated material: 8% Zn, 2·5% Mg, 1·5% Cu, 0·2% Cr.								
		Uncorroded			Non-anodized corroded			Anodized corroded			Uncorroded			Plated corroded			Plated, plating removed on ¾ in. length, corroded		
		E.L.	U.T.S.	El.	E.L.	U.T.S.	El.	E.L.	U.T.S.	El.	E.L.	U.T.S.	El.	E.L.	U.T.S.	El.	E.L.	U.T.S.	El.
Quenched-aged ..		38·9	55·1	19·0	no cohesion			38·5	54·4	19·0	37·5	54·6	24·7	Strong intercrystalline attack					
Quenched and precipitated	10 hr. at 100° C.	51·6	60·5	17·8	no cohesion			51·2	58·8	10·5	50·8	59·8	19·0	44·7	52·8	12·5	46·5	55·0	11·0
	2 hr. at 125° C.	51·7	60·1	17·2	no cohesion			52·8	58·8	10·0	48·2	57·3	17·2	41·3	51·2	12·5	45·8	51·6	7·5
	5 hr. at 125° C.	53·8	61·0	16·6	41·2	42·0	0·5	52·8	58·4	10·0	52·7	59·6	16·1	47·5	56·0	13·0	47·5	52·5	9·5
	20 hr. at 125° C.	57·8	62·6	12·1	48·3	43·9	1·6	55·6	61·0	11·5	54·0	59·9	13·8	47·5	53·0	13·0	51·8	56·0	10·0
	5 hr. at 150° C.	58·3	62·7	12·1	39·8	40·1	1·6	54·8	58·5	7·0	54·2	58·8	13·2	49·7	53·0	12·0	46·2	51·2	10·5

Elastic limit (E.L.) and rupture strength (U.T.S.) in kg/mm². Elongation (El.) in per cent. 1 kg/mm² = 0·635 tons/in².

D. Influence of the Purity of Component Metals.

Zicral prepared from metals of the highest purity is also not corrosion resistant without special protection. A plating alloy made from highest purity metals slightly improves corrosion resistance but in every case, the gain does not justify the expense.

E. Influence of Chromium Content.

Unplated Zicral sheets with different chromium contents were annealed or quenched and aged or heat treated in various ways. They were then corroded, under constant tension, in 3 per cent NaCl in aqueous solution with 0·1 per cent H_2O_2. Some specimens fractured spontaneously after some time, others showed a remaining strength measured in per cent of uncorroded strength. In all cases, alloys with 0·15 to 0·25 per cent Cr additions showed up best. Satisfactory results were only obtained at precipitation temperatures above 125 deg. C. Cr additions above 0·25 per cent are unfavourable. The annealed metal is fairly safe against corrosion.

F. Identification of Alloy and of Precipitation Temperature.

For safety, Zicral must be distinguishable from age hardening Duralumin even if pieces are not externally marked. A solution of 5 gr. Cd-sulphate, 3 gr. Na_2S and 5 ccm. HCl in 100 ccm. total volume is electro-negative compared with Zicral and, after 2 minutes, leaves a black spot on a clean Zicral surface. It is electro-positive against Duralumin and leaves no mark on it.

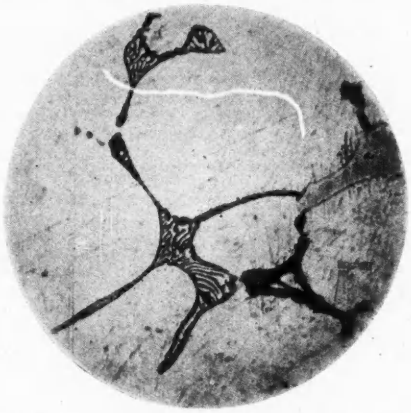


Fig. 2. **Micro-structure of sand-cast Zicral** (× 450).

Unplated Zicral, if age hardened at room temperature, has a Brinell hardness of 160 to 170; if heat treated for 5 hours at 135 deg. C., it has a hardness of 180 to 190. It would be preferable, however, to use distinguishing paint which changes colour according to the temperature reached during precipitation treatment.

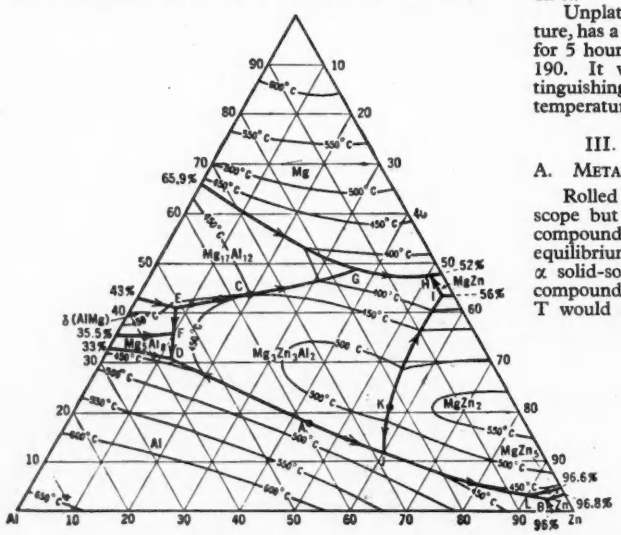


Fig. 1. **Ternary equilibrium diagram Al-Mg-Zn. (Koester).**

III. THE STRUCTURE OF ZICRAL.

A. Metallography.

Rolled or drawn Zicral reveals little under the microscope but sand cast metal shows several intermetallic compounds and one eutectic. According to the ternary equilibrium diagram (Fig. 1), Zicral should show the α solid-solution phase of Mg and Zn in Al and the compound phases T (Mg_3 Zn_3 Al_2) and η (Mg Zn_2). T would appear in eutectic form, η as a result of a peritectic reaction from T. Cu and Cr introduce other phases, and the grey structureless phase, seen in Fig. 2 which is probably due to combined chromium, persists during heat treatment but is broken up by hot work and forms coarse crystals, and starting points of fatigue fractures appear during cold deformation (Fig. 3). The Cr content should therefore be kept low (0·25 per cent maximum); the alloy phases should be properly dissolved

Fig. 3. **Micro-structure of Zicral sheet fractured, during cold pressing, in a region of chromium-rich crystal concentration.** (× 240).

and the chromium should be evenly distributed in the preparation of Zicral. Casting by the continuous process does not noticeably improve chromium brittleness, Mn additions make it worse. The combined percentage of Cr and Mn should be below 0·6.

B. DILATOMETRY.

Tests on Chevenard's micro-dilatometer calibrated against pure aluminium prove that the quench temperature has little influence on the alloy structure. Furthermore, on heating quenched Zicral, one (or two)

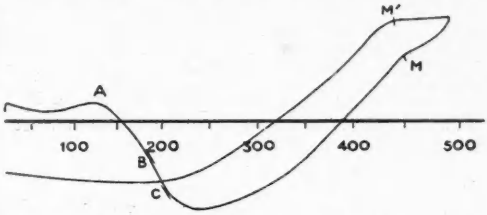


Fig. 4. **Characteristic points on a dilatometric curve of freshly quenched Zicral.**

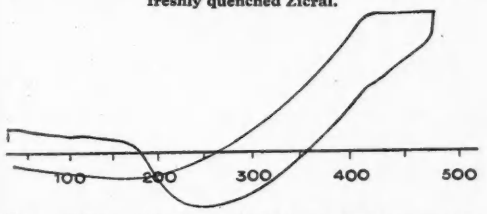


Fig. 5. **Dilatometric curve of Zicral quenched and precipitation heat-treated at 125 deg. C. for 8 hours.**

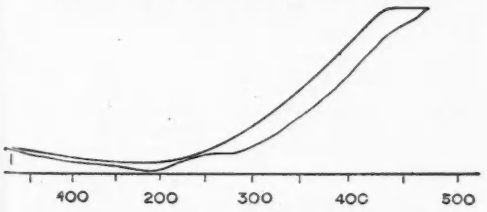


Fig. 6. **Dilatometric curve of Zicral quenched and precipitation heat-treated at 200 deg. C. for 2 hours.**

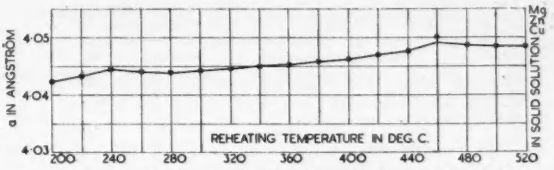


Fig. 7. **Radio-crystallographic determination of lattice parameters of quenched and reheated Zicral.**

precipitations, with a decrease of volume, occur at A (and B) with a maximum intensity between 125 and 190 deg. C. (Fig. 4). At 200 deg. C. the precipitated phases start to re-dissolve and the volume increases again at higher temperatures. A change of slope at M and M' indicates that above 460 deg. C., there exists only one single solid solution. A precipitation heat treated specimen (Fig. 5) shows no hump A and a smaller bulge C because precipitation has largely occurred prior to test. Heating of an over-treated specimen (Fig. 6) produces no precipitation at all, an expansion being visible between 190 and 220 deg. C.

C. RADIO-CRYSTALLOGRAPHY.

Granules of a strictly homogeneous Zicral alloy were cast in ice, heated for 6 hours at 460 deg. C., cooled and then heated to different temperatures and quenched in cold water. Their lattice parameters were determined against quenched 7 per cent Mg-alloy powder as a standard. The Al-structure (α-phase) predominated although some specimens showed the η-phase and also the T-phase in the presence of two interferences. The increase of lattice parameter at 200 deg. C. (Fig. 7) indicates a dissolution of T into η, the increase at higher temperatures, and a progressive dissolution of η into the basic solid solution.

D. X-RAY ANALYSIS.

Chemical and X-ray analyses clearly show the tendency to inverse segregation of Cu and Zn affecting mechanical qualities and corrosion resistance alike. The extent of segregations depends largely on casting procedure and is smallest with metal cast by the continuous process. This process, however, is apt to produce internal stresses which sometimes crack the cast block. Stringent precautions are essential in the production of Zicral.

IV. HEAT TREATMENT OF ZICRAL.

A. SOLUTION QUENCH.

The best quenching temperature for Duralumin is 500 ± 5, but for Zicral 465 ± 30 deg. C., and the greater tolerance is an important practical advantage of Zicral. A short stay at this temperature is sufficient, e.g., 1 mm. Zicral sheet is kept 10 mins. at 465 deg. C. in a salt bath, then quenched. Thick Zicral sections should be heated slowly. Otherwise, the treatment is

TABLE IV.—The mechanical properties of Zicral, for different waiting times immediately before quench.. Zicral with 8·5 per cent Zn, plated with 3 per cent Zn-Al alloy, and rolled to 1 mm. thick sheet.

Waiting Time before quench	Immediately after quench			After precipitation treatment, 5 hours at 135 deg. C.		
	E.L.	U.T.S.	El.	E.L.	U.T.S.	El.
0 sec.	13·0	31·5	21·4	47·7	55	16·3
5 sec.	13·2	31·9	21·4	47·9	55·7	17·6
10 sec.	12·8	31·9	21·0	47·2	55·8	16·7
15 sec.	12·8	32·6	22·0	48·2	54·7	16·0
20 sec.	13·1	32·1	21·1	46·2	52·8	16·4
25 sec.	13·3	31·5	22·5	46·6	53·3	15·3
30 sec.	12·5	30·9	21·1	43·8	52·3	14·7
60 sec.	11·9	28·5	19·6	28·4	42·1	15·4
Complete air cooling ..	10·4	27·1	17·5	13·4	31·4	17·7

as for Duralumin. The time between removing the piece from the furnace and immersing it in the quenching vat should not be much more than 15 seconds (Table IV). The quenching medium controls the cooling rate and supersaturation, and therefore the attainable strength. Water and oil are satisfactory, but still air is not.

B. Age Hardening.

Although not to be used in the age hardened state, Zicral can be cold deformed immediately after quenching and then precipitation heat treated in the final shape. Zicral age hardens more rapidly than Duralumin (Table V) and any cold deformation must be applied immediately after a quench in liquid at a controlled temperature to give maximum deformability.

TABLE V.—Rate of age hardening of Duralumin and Zicral.

Time of age hardening at 20 deg. C.	Duralumin			Zicral		
	E.L.	U.T.S.	El.	E.L.	U.T.S.	El.
5 minutes	15·2	37·3	12·0	26	41·4	13·0
30 minutes	19·0	37·0	12·0	29	46·5	12·5
2 hours	19·6	40·3	12·5	35	51·6	11·5

TABLE VI.—The influence of precipitation treatment on the mechanical properties of Zicral. 1 mm. thick Zicral sheet with 8·5 per cent Zn and 4 per cent Zn-Al plating.

Sheet heated for one hour at 460 deg. C., then water quenched and precipitation hardened at		E.L. kg/mm²	U.T.S. kg/mm²	El. %
125 deg. C. for	1 hour ..	46·9	56·1	19·3
	5 hours ..	48·0	57·2	15·9
	15 hours ..	52·1	58·9	12·1
	24 hours ..	53·2	58·9	12·7
135 deg. C. for	1 hour ..	47·7	56·6	17·2
	5 hours ..	49·9	57·4	14·8
	15 hours ..	51·1	59·0	12·7
	24 hours ..	53·6	58·8	12·7
145 deg. C. for	1 hour ..	49·7	56·8	17·6
	5 hours ..	54·8	57·3	11·9
	15 hours ..	51·8	57·3	11·4
	24 hours ..	52·7	56·0	10·0
155 deg. C. for	1 hour ..	50·1	56·7	17·0
	5 hours ..	54·6	57·1	11·7
	15 hours ..	50·7	55·0	11·0
	24 hours ..	48·2	52·8	10·7

C. Precipitation Treatment.

A treatment of 5 hours at 135 deg. C. gives satisfactory corrosion resistance (Tables II and III) and reasonable elongation (Table VI) without being uneconomical. A special, intentional, waiting period of up to 8 days, between quench and precipitation does not improve the mechanical qualities nor does any of the complicated treatments advocated elsewhere.

D. Annealing.

Annealing for 3 hours at 400 deg. C., followed by furnace cooling at less than 50 deg. C. per hour, produces the best annealed alloy, i.e., plated sheet with 5·5 to 6·5 tons/sq. in. elastic limit, 12 to 20 per cent total elongation, and wire with 7·5 to 9 tons/sq. in. elastic limit, 13 to 15 per cent total elongation. The U.T.S. is 13 to 14·5 tons per sq. in. in both cases. More complicated treatments mentioned in literature show no improvement.

A. Homogenizing Before Quench.

Tests prove that homogenization does not affect the mechanical properties of Zicral but appreciably improves the cold deformability. This deformability is highest if a piece is annealed, during hot work or before cold work, at a temperature just sufficient for complete or nearly complete recrystallization. Tests allowing free deformation, in 5 passes, of a Zicral test tube fitted in an Amsler machine, show that omission of an annealing operation during hot working may actually lead to the elimination of one pass during cold deformation. In the most favourable case, homogenization before hot work allows two more passes to be eliminated. It is during cold deformation that chromium embrittlement leads to fatigue fractures.

V. MECHANICAL TREATMENT OF ZICRAL.

Precipitation treated Zicral cannot be cold worked to any appreciable extent. Cold work of annealed or freshly quenched material rapidly increases the elastic limit, and after 25 per cent reduction, the elongation decreases to less than 5 per cent. A Zicral sheet annealed after working has equal strength in longitudinal and transverse directions. The recrystallization temperature drops appreciably as cold working increases. (460 deg. C. after 20 per cent, 350 deg. C. after 100 per cent, 310 deg. C. after 300 per cent reduction).

VI. MECHANICAL AND PHYSICAL PROPERTIES.

A. Zicral Sheet.

For tensile test data see Table VII. Although showing an acceptable elongation, Zicral has only a small plastic range, and secondary stresses or stress concentrations must be carefully avoided as the metal does not "give" sufficiently to even out stresses. Cold drawing increases the elastic limit and reduces elongation, but the compressive elastic limit, though reduced by slight drawing (5 per cent of elastic limit), increases again with heavier drawing. The modulus of elasticity is 10×10^6 lb. per sq. in.

TABLE VII.—Tensile Test data of Zicral sheet as compared with Duralumin.

	Duralumin	Zicral
Elastic limit kg/mm²	32	50
U.T.S. kg/mm²	42	48
Elongation %	22	15

B. Zicral Bars.

The tensile strength of bars (38 tons per sq. in. elastic limit, 41 tons per sq. in. U.T.S., 9 per cent elongation) is higher than that of sheets because complete recrystallization is unobtainable at quench temperature. Strength values at different temperatures, given in Table VIII and confirmed by tests on an Amsler machine, show, at from 20 to 175 deg. C., a 35 per cent decrease of the elastic limit (18 per cent only for Duralumin) and a threefold elongation of the necked length of the test piece (1·35 times for Duralumin) at the higher temperature. Heating to 140 or 170 deg. C. thus facilitates the deformation of finish treated bars. Higher temperatures would change the precipitated structure.

The limit of plasticity in compression of finish treated Zicral is 45, of non-homogenized Zicral as from the press is 17, of Zicral homogenized before drawing, and as from the press is 14·5 tons per sq. in. At 300 deg. C., the non-homogenized Zicral has a limit of plasticity of 5·8, and the homogenized metal a limit of 5·3 tons per sq. in. Homogenization facilitates cold work but brings improvement neither at higher temperatures, nor for hot work.

The fatigue limit of Zicral is 11 tons per sq. in., the highest of any light alloy. (Duralumin 9 tons per sq. in.).

The resilience measured on Mesnager's test piece, with shock load normal to fibre direction, is 21 to 28·5 lb. per sq. in.

TABLE VIII.—The mechanical properties, at different Temperatures, of Duralumin and Zicral. Tests taken on Ranque's extrusion machine adapted for tensile tests.

		U.T.S. kg/mm²	Elongation of necked length %	Elongation of total test length %	Young's modulus kg/mm²	0·002 % proof stress kg/mm²	0·02 % proof stress kg/mm²	0·2 % proof stress kg/mm²	Reduction of area %
Zicral	20 deg. C. ..	61·2	5·8	4·1	7100	42·0	50·0	58·0	14·0
	100 deg. C. ..	60·1	8·0	5·1	6600	38·0	47·0	56·0	18·0
	140 deg. C. ..	54·3	10·4	7·5	6400	30·0	40·0	49·0	20·0
	175 deg. C. ..	44·2	18·0	9·1	6040	17·0	25·0	38·0	34·3
Duralumin	20 deg. C. ..	47·2	26·8	22·4	6960	25·3	30·0	33·0	42·1
	100 deg. C. ..	44·2	25·8	20·2	6550	22·7	27·0	30·5	44·3
	140 deg. C. ..	42·4	28·7	19·5	6340	20·2	24·5	27·5	50·5
	175 deg. C. ..	46·1	36·3	27·6	5960	14·3	23·0	27·6	53·6

The shear strength, in simple shear, of treated Zicral wire is in the order of 25 tons per sq. in.

The density of Zicral is about 2·80, or 0·10 lb. per cub. ft.

The modulus of elasticity is 10×10^6 lb. per sq. in. at room temperature.

Thermal conductivity (tests of Ranque, Henry, Chaussain) is 0·38 at 20 to 120 deg. C., 0·46 at 200 to 300 deg. C.

The coefficient of linear expansion is very nearly that of pure aluminium, i.e., $23·8 \times 10^{-6}$ at room temperature. Above 75 deg. C., structural changes influence the value of the coefficient.

The friction qualities of Zicral as a bearing metal against steel are good. During progressive running tests of several hours in a pressure lubricated bearing of 1·57 in. diameter, 1·18 in. length, 0·0031 to 0·0047 in. play, under loads up to 950 lb. per sq. in. and at speeds up to 10 ft. per sec., the temperature of the Zicral bearing metal never rose by more than 40 deg. C. Another test with the same bearing at a speed of 3·5 ft. per sec. and under a suddenly applied load of 950 lb. per sq. in. showed that a Zicral bearing needs a longer time than a bronze bearing to establish hydro-dynamic oil film conditions but that temperatures of 100 deg. C. can be attained without damage to the bearing metal. Correct bearing play is more important for Zicral than for bronze bearings.

VII. THE WORKING OF ZICRAL.

A. Hot Work, Forging.

The hot working temperature for Zicral is 380 to 400 deg. C., which is lower than for Duralumin. After the first passes, the temperature can be raised to 420 deg. C. Precautions should be taken as for Duralumin, they should even be stricter in order to avoid cracks. Dies should facilitate metal flow as much as possible.

TABLE IX.—Minimum cold bending radii, in mm., for Zicral sheet. (All sheets in this table can be bent hot, at 380 deg. C., over sharp angles.

	Bending parallel to direction of rolling				Bending normal to direction of rolling			
Thickness of Sheet	10/10	15/10	20/10	25/10	10/10	15/10	20/10	25/10
Sheet annealed	1	2	3	3	1	1	2	3
Sheet freshly quenched ..	1	2	2	3	1	1	2	2
Sheet quenched and precipitation hardened ..	4	6	11	*	4	5	10	*

* Fractured over 20 mm. bending radius.

The mechanical properties of forgings are between those of rolled and drawn material, i.e., the elastic limit 32 to 34, U.T.S. 37 to 41 tons per sq. in., elongation 5 to 13 per cent.

B. Plate Bending.

Table IX gives the minimum cold bending radii for sheets when cracks are to be avoided.

C. Sheet Metal Work.

Cold work is easier on furnace cooled, or even air cooled, annealed sheet than on quenched sheet which is already difficult to work one hour after quenching. The main cold work should therefore be done on annealed sheet and only the finishing operation should be done immediately after the quench and before precipitation hardening. Hot work should be done at 350 deg. C. where plasticity is highest. If the sheet cannot be heat treated after working, deformation should be undertaken at 175 deg. C. and heated tools may be used.

D. Riveting.

Zicral rivets cannot be used. Since the precipitation treated metal cannot be deformed and quenched rivets would age-harden and be subject to corrosive attack. One should use Duralumin F.R. or special rivet Duralumin. These rivets are electro-negative against the Zicral sheet and, with correct dimensioning of rivet and sheet, corrosion can be reduced to a minimum. (Akimov's theory).

E. Welding.

Oxy-acetylene welding, or aluminium brazing, embrittles the material and cannot be applied. Even heat treatment after welding cannot reduce the welding brittleness.

Zicral sheet can be spot welded after pickling. The pickling acid must be well removed to prevent destruction of the plating. Sheets are pickled either by immersion for 13 hours in 30 per cent nitric acid at room temperature followed by rinsing in running water and drying, or by immersion for 3 minutes in a sulphochromatic bath at 60 deg. C. followed by rinsing and air drying. Welds fractured in shear under 285 to 340 lb. per spot (10 to 11·5 tons per sq. in.) on 1 mm. thick sheet, show results comparable to, though more consistent than, those obtained on Duralumin. Unplated edges must be puttied and painted in order to avoid access of humidity to the weld points with consequent intercrystalline corrosion and destruction of the weld.

VIII. CONCLUSIONS.

Zicral is an important new light alloy of very high mechanical properties. Difficulties in rolling Zicral require special precautions in the manufacture of the material, and the small plastic range requires a new conception of design and assembly methods. These disadvantages can be overcome or minimized with sufficient care. The advantages of high static and fatigue strengths will then justify the use of Zicral in high-performance engines and for the lightening of light-alloy structures, especially in aircraft engineering.

U.S.A.

Liquid Cooling of Turboalternators

By C. J. FECHHEIMER. (From *Electrical Engineering*, No. 10, October, 1947, pp. 969-974, 2 illustrations.)

UNTIL some 15 years ago many operating and manufacturing engineers were skeptical about the safety of hydrogen as a cooling medium. To-day these fears are dispelled and practically every large turbine generator is hydrogen-cooled.

Present day engineers look askance at the idea of liquid cooling, especially for the rotors of turbine generators. It is feared that the liquid cannot be made to pass into, through, and out of a high-speed rotor without giving trouble.

It is recognised that, aside from magnetic saturation and mechanical stresses, the temperature rise of the rotor winding imposes the limitation as to the overall dimensions when the load current lags behind the voltage. For, to decrease the D^2L (where D is the rotor diameter and L is the rotor length) it is necessary to increase the ampere turns, and that gives rise to increased copper loss. Thus, one principal gain to be affected by liquid cooling of the rotor is that the copper loss can be increased for a given temperature rise, and the machine can be made smaller, lighter, and cheaper for a given rating.

liquid is cooled in some established heat exchanger, and in series therewith is a pump and some device for removing entrapped air (or other gas.)

Fig. 1 shows the stationary metal tube *A-B*, which clears the bore in the shaft, welded to the plate *C*, which in turn is bolted to a rigid stationary plate *D*. The liquid flows from *A* to *B* and is discharged near *B* into the pocket *E*. It then passes through the radial holes *F* and *G*, into the casing *H*, then flows radially outward and then into axial ducts *J* and *K*. These ducts, *J* and *K* are the main cooling ducts and extend the full axial length of the rotor body. The liquid then flows radially inward to *H'*, through radial holes *G'* and *F'*, then axially through the hole *L* in the shaft, to the discharge radial holes *M*. It then collects in the annular space, *N*, and later it passes through the external pump and heat exchanger in the external part of the circuit, back to the entrance tube *A-B*.

During the passage of the liquid through the rotor body, the centrifugal action thereon at the incoming end (*H* to *J* and *K*) is balanced substantially by the centrifugal action at the leaving end (*J* and *K* to *H'*). How-

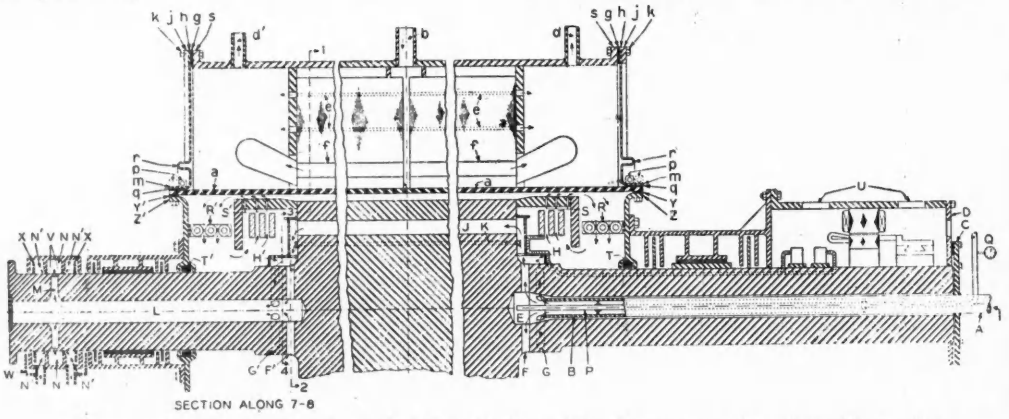


Fig. 1. **Turbine end (left) and exciter end (right) of liquid- cooled turbine generator shown from side elevation.**

A second important gain is that the rotor copper temperature will be nearly uniform, both radically and longitudinally, and consequently there should be no damage or deformation due to differential expansion and contractions, as in gas-cooled rotors.

A minor advantage is that the temperature of the copper and the steel above that of the entering liquid can be predicted within only a small percentage of error, if the losses and the various constants of the materials are known.

For a given internal stator diameter and for given magnetic densities and voltage, the stator external diameter can be made smaller than for gas cooling.

Other advantages of liquid cooling are : stator copper temperature is nearly uniform ; there is absolutely no corona ; the stator may be wound for considerably higher voltage than is practical with gas cooling ; the rate of flow of the liquid can be regulated readily, and thereby the temperature rise of the stator winding can be controlled to a large extent ; and the internal reactances are higher than with gas-cooled machines, thereby admitting of smaller external reactors, or possibly their omission.

ROTOR CONSTRUCTION.

The same liquid is used repeatedly in a closed circuit system. In the external part of the circuit, the

ever, the head generated in the centrifugal pump at *M* is not balanced at the other end. This head generated from the shaft bore to the shaft external periphery is considerably more than is needed to overcome the sum of the hydraulic resistances opposed to the flow of the coolant from the entrance at *E* to the discharge in *L*.

The large centrifugal action between the shaft bore and the rotor ducts will cause entrapped gases to collect in the pocket *E* at the incoming end. The gases then are drained off through the small stationary tube *P* and can be allowed to issue through a suitable trap. To ensure that the gases escape, the pressure at *E* should be slightly above atmospheric but should not be so high as to cause the liquid to flow out between the shaft bore and the external periphery of the tube *A-B*. The pocket *E* is enlarged so that centrifugal action will cause the liquid to flow into the radial holes *F* and *G* and not into the annular space between the shaft bore and the tube *A-B* even with the pressure in *E* slightly above that of the atmosphere.

There is appreciable resistance to the flow of the liquid through the rotor ducts, but with suitable proportions the pressure in the shaft bore should be appreciably above a vacuum.

If the shaft diameter is determined by a usual value of working stress in torsion for the transmitted load, for a large generator at either 3,600 or 1,800 r.p.m., the

head generated by centrifugal action at *M* is several times the equivalent of sea level atmospheric pressure. Consequently, there would be danger of cavitation in the shaft bore at the turbine end if there were no provision for absorbing the additional head. This is secured by restricting the discharge ducts near the shaft periphery by means of orifices. To prevent cavitation at the entrance of the radial ducts *M*, the velocity of the liquid is made low by making the entrance section relatively large and then curving, so as gradually to accelerate the liquid.

After the liquid is discharged from *M*, it enters the annular space *N* at high velocity. This space fills rapidly and the liquid whirls and most of its kinetic energy is dissipated as heat. The calculated mean temperature rise of the liquid due to this loss usually will be less than one degree centrigrade. This means also that the power required to drive the centrifugal pump *M* is small and decreases the generator efficiency by an extremely small amount.

The liquid next passes through the restricted areas *V* between the two annular spaces *N* and *N'*, and finally is discharged from the bottom of *N'* into suitable pipes, whence it flows into the heat exchanger and external pump, and is returned to the entrance tube at *A*. The whirling rings *X* should prevent the axial escape of liquid while the rotor is running at normal speed. When the machine is being prepared to run at or is near standstill, there may be a small escape of liquid. Practically all of this may be caught in the gutters *W* and returned to the main part. There also may be a little leakage near the entrance at *C* although this can be eliminated substantially by suitable gaskets or caught in gutters and returned. It will be noted that at standstill, or very low speed, the flow is produced by a low-pressure external pump. Consequently, the volume of flow is less than when running at normal speed, and the leakage is very small. Although the volume of flow is less at very low than at normal speed, the temperature rise of the copper (above the ingoing coolant) for a given copper loss should be nearly the same since the dust surface drop and temperature rise of the coolant are small.

The ducts in the rotor body, *J* and *K*, are rectangular in section or trapezoidal. The arc machined from the external cylindrical surface and the outer parts of the *J* ducts are filled subsequently by steel pieces, suitably welded in place. The small ducts, K, below the winding slots are cut in after the main winding slots are machined, and their outer parts are covered with thin plates welded in place at the bottom of the main slots. One of the larger ducts is in each of the rotor teeth, and in the central pole adjacent to the last slots. A small duct is located below each rotor slot.

In order to absorb the heat generated in the coil ends of the rotor windings, the gas at the ends is caused to circulate by centrifugal action, passing through holes, *S*, in the retaining rings, and passing over the surfaces of circularly bent tubes and between fins on the tubes *R* and *R'*, in a continuous closed circuit. These finned tubes are stationary and are supported, as indicated. Water or other liquid is circulated within these coils to absorb the heat. The finned tubes may be placed in some other location in the gas stream.

In order to reduce the windage loss, to improve the heat conductivity of the insulating wall in the rotor slots, and to improve the heat transfer between rotor coil ends and the circulating gas, and between the gas and the finned tubes *R* and *R'*, the rotor is operated preferably in a hydrogen atmosphere. The gland seals for minimizing the escape of hydrogen and infiltration of air are indicated at *T* and *T'*.

With this construction, calculations of the heating of the rotor coil ends in one atmosphere of hydrogen indicate that, when running, those parts will have about the same order of temperature rise as the copper in the embedded parts.

Fitting snugly in the stator bore is a cylinder, *a*, of insulating material. The flanged disks *Z* and *Z'* are bolted to this cylinder, being separated therefrom by suitable gaskets, *Y* and *Y'*. Thus, *a*, *Y*, *Z* and *T* (and *a*, *Y'*, *Z'* and *T'*) form the inner sides of the structure wherein the hydrogen gas is retained.

STATOR CONSTRUCTION.

The coolant is an insulating liquid, either transformer oil or some non-inflammable liquid which is circulated in a closed system, with an external pump and a suitable heat exchanger in series. The liquid enters at the middle, at *b*, and is discharged at both ends, at *d* and *d'*. For some ratings the liquid may enter at one end and be discharged at the other end.

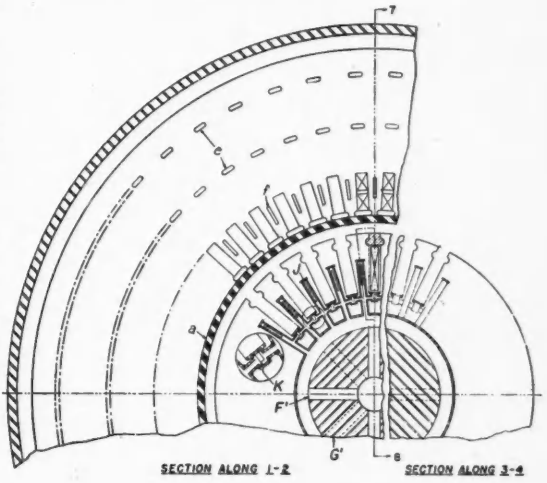


Fig. 2. **Front elevation of rotor and stator of liquid-cooled turbine generator.**

Axial ducts are provided in the laminations, at *e* and *f* in Figs. 1 and 2, the proportions of which are predetermined from the magnitude and distribution of the losses to be absorbed, from the physical properties of the coolant and from the assumed temperature rises.

The insulating walls of the stator coils can be made of materials like those used for transformer coils for the same voltage. The wall thickness is then less than with air or hydrogen as the cooling medium. Furthermore, the liquid coolant reduces the lamination temperature below that obtainable with hydrogen. Because a duct is in each tooth the coolant is close to the coil, and consequently the permissible thermal drop through the insulating wall may be higher than for hydrogen.

Owing to the much better thermal properties of the coolant the ducts (*e* and *f*) may be of such reduced proportions that the space occupied by them is very small as compared with the space for the ducts in a hydrogen-cooled machine.

The ducts *f*, in the teeth, do not add to the external diameter. This fact, plus shallower slots, plus much less space for the ducts in the core, permit of a smaller external diameter of the stator laminations for given internal diameter, magnetic densities, and stator voltage.

The stator is closed at each end by the diaphragm, *h*, which is separated from the frame flanges by means of a fluidtight oil resisting gasket, *g*. The rings, *j*, are interposed between the heads of the bolts, *k*, and the

outer surfaces of the diaphragms, *h*. The diaphragms have axial flanges, *m*, whose internal diameter is nearly the same as the bore of the stator laminations, and are separated from the cylinder, *a*, by means of gaskets, *q*. These flanges are pressed hard against the cylinder, *a*, through *q* by means of two clamp rings. The flanges of these two rings are not in the same location circumferentially to ensure positive pressure on the gaskets for all peripheral positions.

An advantage of the high dielectric strength of the stator coolant is that the stator can be wound for higher voltage than is the present practice in the United States.

HEAT ABSORPTION AND TRANSFER.

The thermal gains to be effected by some liquids over air or hydrogen for cooling are enormous. The volume per unit of time, as adopted for machines, with liquids, would be much less than with gases. The velocities also would be lower and the duct sections and surfaces smaller, but even so, the temperature rise of the coolant and the thermal drop from the duct surface to the coolant are much smaller than with gases. Oils are inferior to water as coolants, but greatly superior to gases.

It would be desirable to operate the rotor cooling system in parallel with the lubricating system. Unfortunately, the viscosity of the bearing oil considered is such that the flow in the ducts probably would be laminar, and therefore the heat transfer rate would be lower than the values for which turbulent flow was assumed. Other petroleum oils have been given consideration, and it appears that some of them have possibilities.

Without doubt, water is the best liquid coolant for the rotor from the thermal standpoint. The objection that may be raised is that it might cause corrosion or scaling of the steel surfaces. However, with a suitable inhibitor, and with the conditions obtaining in this application, such will be practically negligible. These conditions are : only distilled or deionized water with proper inhibitor will be used ; it will operate only in a closed system ; and the temperature of the liquid will not exceed 70 degrees centigrade in any place in the closed circuit.

An important point is that with the large drop through the insulation there should be substantially uniform thermal conductivity of the insulating wall in order that this drop will not vary.

ROTOR TEMPERATURE DISTRIBUTION.

If the copper is preheated at standstill, or at very low speeds, so that full load copper temperature is attained, and the rotor is brought up to speed, without change in temperature, after which the same, or nearly the same, temperature is maintained, and if the cooling is the same at very low speed as at full speed, and if the copper and steel temperatures are uniform (though different from each other) then there will be no deformation due to expansion or contraction of the copper.

These conditions cannot be met in large modern gas-cooled machines, because such machines are provided with internal fans.

According to calculations, with water as coolant, the radial differences of copper temperature can be kept to less than five degrees centigrade, and the calculated difference between the steel temperature at standstill and when running is of the order of only two degrees centigrade, assuming excitation for full load in either case. It seems highly probable that there should be no deformation with water as the coolant, with careful proportioning, and with proper preheating, and with soft copper, provided the current in the rotor winding is maintained constant when it is running.

At the present writing there is no intention to state what are the limits of either hydrogen- or liquid-cooled rotors. But it seems evident that dangers from deformation can be eliminated from a liquid-cooled rotor. Also, short-time large changes in rotor current will not cause deformation owing to the storage of heat in the copper. These statements are for soft copper, and limits as to change in rotor current are greatly increased with hard-drawn copper.

STARTING PROCEDURE.

In a new machine, initially all ducts are filled with air. The insulating liquid coolant for the stator is caused to circulate with the aid of the external pump, there being a suitable vent outside to allow air to escape. It is advisable to cause the liquid to enter a vacuum tank, or other de-aerating device, before it passes into the stator, so as to exclude the air. Moisture also should be removed, as is the usual practice with transformers. The suggestion is offered to have instruments to indicate the pressure and volume of flow at all times. The coolant should be in the stator long enough to ensure that it has penetrated the insulating walls before the machine is started.

Hydrogen should be introduced around the rotor and maintained for a sufficient length of time for it to penetrate the rotor's insulating walls. With the rotor stationary, the rotor coolant should be circulated long enough to ensure the expulsion of air everywhere. If water is the coolant, it should be distilled or deionised and treated with a suitable inhibitor. The volume of liquid per unit of time at standstill will be less than when running. The pressure needed for driving the liquid through the ducts at standstill is not large, and suitable gaskets are provided to eliminate leakage, or reduce it to a very small amount. At the discharge at *N'* the pressure will have dropped so that the leakage there will be very small. What does leak will be gathered in the gutters, *W*, and drained into the outlet.

When there is assurance that the rotor liquid is circulating without entrapped gases, the rotor is rotated at very low speed, and then electric current is caused to flow in the windings. The flow of the coolant through the rotor ducts should be maintained. During this preheating operation there should be little or no primary water flowing in the heat exchanger, so that the temperature of the coil ends will not differ greatly from that of the embedded parts. The resistance of the winding should be measured by voltmeter-ammeter method at various times and it is advisable to have a continual check on the resistance when at full speed.

When full load rotor copper temperature is attained, the rotor should be brought up to speed, care being taken to adjust the excitation so as not to generate too high voltage. The generator should be synchronized rapidly and loaded, so that there will not be a large change in rotor temperature. The flow of primary water in the heat exchanger should be started or increased when full speed is approached.

CONSTRUCTION COMPARISON.

For a given D^2L there are some added costs, and some reduced costs of liquid-cooled generators contrasted with hydrogen-cooled. Liquid-cooled machine reduced costs result from omission of : internal fans, internal end-bell walls, large internal coolers, multiplicity of vent ducts for stator and rotor, and duct work for flow of coolant to and from internal heat exchanger ; also the outer end bell costs are much less because of the considerable reduction in diameter, with the end bells designed to withstand explosion pressure. Added costs result from : machining of ducts in rotor (nearly offset by machining of rotor vent ducts for hydrogen), welding of ducts and casings which must be leak proof, insulating cylinder in stator bore, external heat exchangers for stator and rotor, and internal heat exchangers *R* and *R'*, and pumps and de-aerators for both stator and rotor.

The writer is of the opinion that, for equal D^2L, there will be little difference in first cost. But the smaller D^2L for a liquid-cooled machine should make the cost appreciably lower. Of course, the reduction in floor space is also important to power companies.

The 300 MW Standard Power Stations of the German Wartime Emergency Building Program

By E. KIEGER. (From *Elektrotechnik und Maschinenbau*, Austria, Vol. 64, No. 7/8, July/August, 1947, pp. 105-113, 4 illustrations.)

GENERAL.

WHEN, in 1942, the German Government realized that the electric power resources of the country had become inadequate to deal with rapidly increasing electricity requirements and that Germany was faced with a complete industrial dislocation of its already highly strained economy, it decided to provide, with the shortest possible delay, the largest possible amount of new generating capacity. Therefore an emergency building program was drawn up by representatives of the plant manufacturing, as well as the electricity supply, industry and it was decided that a total of 13 power stations, each with a final capacity of 300 MW, should be built on hard and brown coal fields. These power stations were to be standardized, so that the highest economy in construction and in operation, as well as speed in construction and the interchangeability of parts, would be obtained. They were also to incorporate the latest technical developments.

Difficulties in designing a standard power station were manifold. The stations were to be built in different parts of the country ; some to fire brown coal, others hard coal, and some a type of coal which was between hard and brown coal. Some stations were to derive their cooling water from rivers, and others were to use recirculation.

Table I. gives a list of the projected stations and indicates the type of coal, the type of cooling, the location, and the prospective owners.

TABLE I.

Power Station	Company	Location	Cooling
	A. BROWN COAL.		
Herkules ..	ASW	Saxony	Fresh water/recirculation.
Fürstenberg ..	MEW	Brandenburg	Fresh water.
Trattendorf ..	EWAG	Brandenburg	Recirculation.
Frimmersdorf	RWE	Rhine/Ruhr	,,
Weisweiler ..	RWE	Rhine/Ruhr	,,
Lübbenau ..	EWAG	Spreewald	,,
Wöllan ..	EV-Süd	Steiermark	,,
	B. HARD COAL.		
Wilhelm ..	EVO	Upper Silesia	Recirculation.
Walter	EVO	Upper Silesia	,,
Saar	—	Saar	,,
Vienna ..	WEW	Vienna	Fresh water.
Berlin-Havel ..	BEWAG	Brandenburg	,, ,,
Havelberg ..	MEW	Brandenburg	,, ,,

Four types of boilers were contemplated and Table II. indicates the type to be used for each individual station and also gives the corresponding brief fuel analysis.

On technical and economic grounds it was decided to install the required 300 MW per power station in 4 topping turbines of 25 MW capacity each and 4 condensing turbines of 50 MW capacity each, one topping and one condensing turbine always operating as one unit of 75 MW maximum continuous rating, and to feed each of these units from two boilers of 145 tons/hour individual normal evaporation, but capable of a sustained output of 160 tons/hour.

BOILER PLANT.

Both the boilers for brown coal and for hard coal were designed as single-double flue types—the double flues reaching only down to the boiler-room operating floor so that the space below could be used for the coal mills. The block dimensions of a boiler for higher grade coal were :—

Width	..	10 metres.
Depth	..	20 ,,
Height	..	31 ,,

The boilers for lower grade brown coal had the same dimensions, only their height was increased. The interior design differed, of course, because of the recirculation of the flue gases, etc. To maintain a uniform design for the flues, the flue joints were, however, made in the same position as in the boilers for higher grade coal.

The boilers for brown coal and for good hard coal were fitted for corner firing with 4 mills per boiler. The coal mills were normal crushing mills, installed in one line, each mill having 4 ducts to the corresponding corners of the furnace. The capacity of the mills was such that the rated boiler output could be maintained with only three out of its four mills in operation.

The medium coal boilers were also designed for corner firing, and were fitted with individual drum mills and intermediate bunkers. Slag tap furnace firing with very high furnace temperature was, at one time, suggested for this type of coal, but not adopted.

The decision to allow the installation of natural or forced circulation boilers, whichever might be more appropriate for the individual station, made standardization more difficult. The maximum operating pressure for natural circulation boilers was 125 atü*, and for forced circulation boilers 140 atü. Manufacturers had to guarantee a superheated steam temperature of 500 deg. C. down to an output of 100 tons/hour for all boilers. The reheaters (contact reheaters) were designed for 100 per cent of the steam output and for reheating from about 280 deg. C. to 425 deg. C. The required air temperature of 400 deg. C. was obtained in boilers for normal brown coal by means of conventional air preheaters. Boilers with flue gas recirculation were fitted with Ljungström air preheaters to allow the boilers to be kept within the standard overall dimensions.

* 1 atü = 1 atmosphere gauge = 14·2 lb. per sq. in. gauge.

TABLE II.

Boiler for :	Power Station	Fuel			
		Calorific value Cal/kg.	Water per cent	Ashes per cent	Ash melting point, deg. C.
Brown coal, without recirculation of flue gas	Herkules Fürstenberg Trattendorf Wöllan Lübbenau	1800 and over	Up to 55	Up to 20	1000 and above
Brown coal, with recirculation of flue gas	Frimmersdorf Weisweiler	1550 and less	Over 55	Up to 20	1500 and less
Hard Coal	Vienna Havelberg Berlin-Havel	5500 and over	Up to 12	Up to 15	1100 and over
Medium Coal	Wilhelm Walter Saar	4500 and less	Over 12	Over 15	1100 and less

The following flue gas end temperatures had to be guaranteed :—

Brown coal ..	180 deg. C.
Good Hard coal	160 deg. C.
Medium coal ..	180 deg. C.

The induced draught fans were of the axial or the radial type, with guide vane regulation. They were driven by three-phase pole changing motors because commutator motors and hydraulic gear could not be used owing to delivery difficulties.

Flue gas cleaning was done by means of electric precipitators, as only one type of these was required regardless of the type of fuel used.

COAL HANDLING EQUIPMENT AND ASH REMOVAL.

The arrangements for coal storage and for coal delivery had to suit the local conditions of each station and their design was, therefore, left to the discretion of the individual companies. Coal was to be delivered from the deposit, via mining machinery and belt conveyors, to a central crushing plant. Over three belt conveyors—(this number was necessary as a precaution against air raids)—the crushed coal is delivered to a gallery directly above the coal bunkers of the individual boilers. The latter are built as low level bunkers directly against the outer wall of the boiler-house, and the bunker capacity corresponds to 12 hours' consumption at full load. The distribution of the coal between the bunkers of the individual boilers is done by reversible conveyor belts.

The individual coal mills are fed from the low level bunkers by conveyor belts and distributing gear, and the latter operated by d.c. motors. Owing to the size of the power stations, only pneumatic or hydraulic ash removal could be contemplated. The choice between these two systems was left to the discretion of the prospective owners.

STEAM TURBINES.

For the total maximum continuous rating at each station of 300 MW, four sets—each consisting of one topping turbine of 25 MW and one condensing turbine of 50 MW—were planned. The steam conditions at the turbines were :—

At the inlet of the topping turbine ..	111 ata.†, 490 deg. C.
At the exhaust of the topping turbine ..	20 $\pm$ 1·5 ata.
At the inlet of the condensing turbine	18·5 $\pm$ 1·5 ata., 415 deg. C.

By fixing the back pressure of the topping turbine and the steam conditions at the inlet of the condensing turbine, the relative outputs of these two turbines were determined. However, as it was decided to have the same steam conditions at the inlet of the condensing turbine, whether this was installed in a station with fresh water cooling or not, the relative outputs of topping and condensing turbines were different for the two types of station. Where recirculation cooling was used, the economic output of one group was 0·8 $\times$ 75 MVA = = 60 MW. In the case of fresh water cooling and with the same throughput of steam through the topping turbine, a higher output could be obtained from the condensing turbine, but, as the machines to be used in the two types of stations had to be of exactly the same design, the smaller steam consumption in the case of fresh water cooling resulted in the topping turbines and the boilers in these stations not being fully utilized —or the condensing turbine could be operated at a load higher than 50 MW provided the power factor was improved.

Whilst the topping turbines were designed as single cylinder units, the condensing turbines were designed as two-cylinder units with three unregulated tappings at 7, 3 and 0·5 ata, respectively, for feed-water preheating. The cooling water temperatures were stipulated, as usual, at 12 deg. C. for fresh water and 27 deg.C. for recirculation cooling, corresponding to an air temperature of 15 deg. C. and an air humidity of 70 per cent. Assuming the cooling water requirements as 70 times the amount of steam condensed in the condenser at the economic load, these amount to about 11,000 m³/hr. for fresh water cooling and about 11,300 m³/hr. for recirculation cooling. From this follows a vacuum of 96·5 per cent (0·035 ata) and 93·5 per cent (0·065 ata), respectively.

Each half-station (150 MW) is provided with four cooling pumps, with an aggregate capacity of 60 per cent of the capacity needed for the whole station ; as an air-raid precaution, these pumps were housed in four separate and dispersed pump houses.

FEED-WATER PREHEATING.

Each block, consisting of two boilers, and topping and condensing turbines, was provided with its own feed-water preheating. Apart from a back pressure range of about 3 ata, to which all the steam turbines driving the feed-water pumps were connected, there was no steam cross-connexion between the individual blocks.

The feed-water preheating system consists of four stages.

(1) The low pressure preheater, fed from the lowest tapping at about 0·5 ata.
(2) The pump preheater supplied from the back pressure mains of the turbines driving the feed-water pumps and from the intermediate unregulated tapping (3 ata) of the condensing turbine.
(3) The intermediate pressure preheater connected to the highest (7 ata) tapping of the condensing turbine.
(4) The direct-contact preheater with de-aerator, fed over a pressure reducing valve from the 18·5 ata range, after the reheater ; the pressure is kept constant at 12·8 ata, corresponding to a final feed water temperature of 190 deg. C., by a pressure regulator.

The fourth stage is, at the same time, designed as a feed-water accumulator with a capacity of 100 m³ corresponding to 20-minutes' consumption of one block at 300 tons/hr. evaporation. There were two accumulators of about 60 m³ volume each per block.

Each block is provided with one single-stage evaporator designed for 5 per cent of the economic load.

To supply steam for the thawing-out of frozen raw coal, two heat exchangers were installed in each station and so dimensioned that thawing can be done in two shifts.

Each half-station of 150 MW had, as boiler feed-water pumps, four turbo-pumps of 160 tons/hr. capacity each (one to each boiler) and two electro-pumps of 160 tons/hr. capacity each (delivering into one common emergency mains). All the pumps are of identical design and run at a speed of 3,000 r.p.m. When driven by turbines speed regulation is used, but when electrically driven regulation is by throttle valves.

The delivery pressure was 140 atü for natural and 180 atü for forced circulation boilers. Under normal conditions the turbo-pumps were used, operating on steam tapped from the intermediate pressure range after the reheater, whilst the electro-pumps serve only as stand-by units. The feed pump turbines exhaust into a common 3 ata back pressure steam range, in parallel with a pressure-reducing plant. The central

† ata = atmospheres absolute.

tapping of the condensing turbine is designed for direct connexion to evaporator and pump preheater, but also to the 3 ata range directly. This design was adopted because the exhaust steam from the feed-pump turbines could not always be accommodated in the preheaters and the evaporators. Fig. 1 shows one 75 MW block diagrammatically.

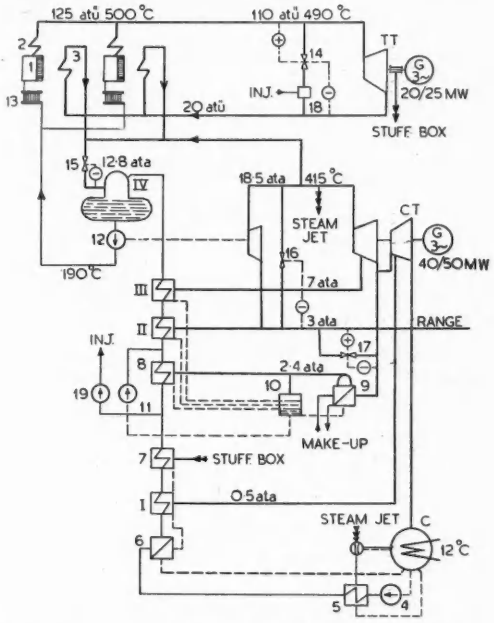


Fig. 1. **Diagrammatic arrangement of the 300 MW standard power station.**

The steam heated to 500 deg. C. in boilers 1, and superheaters 2, was supplied to the topping turbine TT. There it gave 20/25 MW and its pressure was thereby reduced to about 20 ata. From the outlet of this turbine the steam returned to the boilers where it was reheated to 425 deg. C. in the reheaters 3. From the reheater it flowed to the condensing turbine CT and thence to the condenser C where it was condensed by cooling water of 12 deg. C. (in the case of fresh water cooling) at about 0·035 ata. The condensate (of about 22 deg. C.) was pumped back to the feed water preheating plant by pump 4. Between steam jet condenser 5 and the low pressure feed-water preheater I, there was a drain cooler 6 for extracting the remaining heat from the condensate of the labyrinth steam (condenser 7) and from the L.P. condenser, to transfer it to the turbine condensate. The L.P. preheater, supplied from the lowest tapping of the turbine, heated the feed water to about 80 deg. C. The labyrinth steam of the topping turbine was also made use of for feed-water preheating and gave up about 4 kcal per kg. of turbine condensate.

In the condenser 8 the make-up water evaporated in the evaporator 9 (through steam at 2·5 ata taken from the 3 ata range) re-condensed and also gave up its heat to the feed-water.

In the preheater stages II (pump preheater) and III (intermediate pressure preheater) the temperature of the turbine condensate was raised to 160 deg. C.

The condensates from the intermediate pressure preheater III, the pump preheater II, the condenser 8 and the heater condensate of the evaporator 9 were all collected in one container 10 which was at the pressure of the condenser 8. From there they were pumped into the flow of the main condensate by a pump 11. The main condensate, at a temperature of 160 deg. C, was then first de-aerated in a de-aerator—stage IV—at a pressure of 12·8 ata and collected in a hot accumulator of which the de-aerator actually forms a part. It remained at the pressure of 12·8 ata with the corresponding temperature of 190 deg. C. From the accumulator the feed-water flowed directly to the boiler feed-water pumps 12 which forced it through the economizers 13 into the boilers.

PRESSURE REDUCING AND HOT STEAM COOLING PLANT.

Water for the steam coolers was taken from the high pressure feed-water pipes and not as pure condensate from the turbines over special injector pumps.

Two 111/20 ata throttle valves (14) are installed in parallel with each topping turbine. There is also one 18·5/12·8 ata throttle valve (15) for each block to supply superheated steam to the de-aerators. Finally, there is one 18·5/3 ata throttle valve (16) in each half station to safeguard the pressure in the 3 ata mains in the case of a deficiency of steam at this pressure (e.g. when the electric and not the steam feed-water pumps were in operation).

Immediately after each 111/20 throttle valve was a steam cooler (18) the purpose of which is to protect the piping against too high live steam temperatures. The injected water was tapped from the condensate pipe after the labyrinth steam condenser (7) and forced into the coolers by injector pumps (19).

RUTH'S STEAM ACCUMULATORS.

As steam accumulators must be laid-out to suit the electric load conditions, it was left to the owners of the individual stations to order equipment according to their particular requirements. For instance, in the case of the Trattendorf station (with considerable peak loads from electric traction) one accumulator of about 90 m³ capacity was needed for each generating block. In stations with forced circulation boilers it was intended to use the accumulators for starting-up purposes also.

FEED-WATER TREATMENT.

Feed-water treatment had to be designed for each station individually as, owing to their different locations, different chemical compositions of the raw water were encountered. Standardization took place only in so far as that, in all cases, gravel filters were used for the purification of the cooling and general supply water. It was also decided that, in all cases, the basic exchange softeners were to be employed for conditioning the feed-water. In addition, water decarbonization plant had to be installed in some of the stations.

PIPES.

The pipe lay-out was standardized for all stations and was designed for the use of the smallest possible number of sizes. Altogether, only 10 different sizes of steam pipes and 13 different sizes of water pipes (including feed-water, condensate and raw water pipes) were used.

GENERATORS AND TRANSFORMERS.

The topping generators are ordinary standardized generators for 32 MVA, and the main generators are standardized generators for 64 MVA with a power factor of 0·8. As, in some of the power stations, a power factor of more than 0·8 could be expected, the generators in such cases can supply more than 25 and

50 MW, respectively. In the case of the topping turbines, this can be achieved by increasing the steam pressure, and in the case of the condensing turbines by increasing the intermediate pressure or, where fresh water cooling was used, by improving the vacuum. The generators are fitted with lateral air coolers. The necessary cooling water is tapped from the main cooling water supply before it reaches the condensers and is pumped through the air coolers by special pumps.

The 32 MVA generators are designed for a generating voltage of 6·3 kV, the 64 MVA generators for 10 5 kV. Each generator is connected by bare bus-bars directly to a generator transformer of the same capacity which, on its high voltage side, is connected to the adjacent open-air sub-station.

HOUSE SUPPLY INSTALLATIONS.

The total installed motor capacity of each half-station (150 MW) is about 16,000 kW, of which about 13,000 kW are high voltage motors (over 100 kW). The electric load of these motors (at 150 MW output per half-station)—assuming that both electric feed pumps are in operation and that the corresponding power factor is 0·786, and taking into account that not all motors are in operation or at full load simultaneously —is 18,000 kVA, of which about 15,700 kVA are consumed by the high voltage motors.

It had been decided not to instal any house turbines. Therefore, the station's consumption has to be taken from the 100 kV section of the open-air sub-station through 100/6 kV transformers.

The sub-stations are, therefore, provided with a third kV bus-bar from which only the house supply is taken, and to which any generator of the station can be connected.

Two 100/6 kV house transformers of 20 MVA capacity each are provided for one half-station, and three such transformers for a complete station, allowing for a stand-by capacity of 100 per cent and 50 per cent, respectively. In addition, at least one 20 MVA connexion to an outside grid was made and emergency supplies for starting up were provided. The two voltages of the house supply system are 6 kV and 380 V.

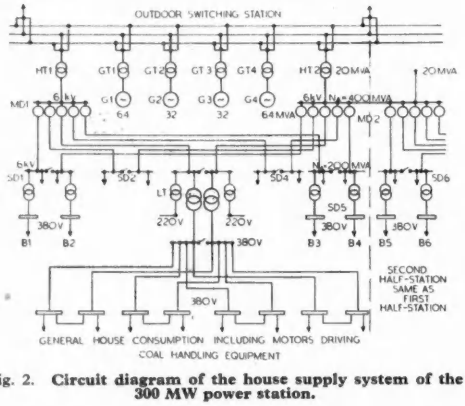


Fig. 2. **Circuit diagram of the house supply system of the 300 MW power station.**

Fig. 2 shows the circuit diagram of the house supply system ; air raid precautions influenced its design to a very considerable extent. The 6 kV part is subdivided into three single bus-bar systems separated from each other. The first house transformer HT 1 feeds into the main distribution switchboard MD 1 of the left half of the station (which alone is shown in the diagram). The third house transformer HT 3 feeds into the corresponding second half of the station. Transformer HT 2, which is the stand-by house transformer, and the line FA from the outside grid feed into the central part and into the stand-by distribution switchboard which has twice the number of connexions compared with MD 1.

The individual consumers were divided into 5 groups per half station, namely :—

Sub-distribution 1 (SD 1) : boilers 1 and 2, including all 6 kV and 380 V ancillaries necessary for the operation of the boiler block. The 380 V part is supplied from 2 transformers, each of which is laid out for the requirements of one boiler only.

Sub-distribution 2 (SD 2) : comprising all the high voltage motors in pump-house 1 of one half-station.

Sub-distribution 3 (SD 3) : comprising the general house consumption of one half-station. The high voltage motors connected to this section comprise the motors driving the coal handling equipment. The 380 V supply is taken from two transformers of 1,200 kVA capacity each, one of which is always kept in reserve. In addition, two lighting transformers 6,000/220 V—one of which was always kept in reserve—also form a part of this sub-distribution system. The two lighting transformers LT are each connected to an independent lighting system.

Sub-distribution 4 (SD 4) supplies the high voltage motors of the electric feed pumps and the motors of the condensate pumps of one half-station.

Sub-distribution 5 (SD 5) supplies boilers 3 and 4 in the same way as sub-distribution 1 supplies boilers 1 and 2.

The house supply arrangements in the other half-station correspond exactly to those in the first half-station.

All the sub-distribution units are in turn each divided into two parts ; the first part is supplied from the main distribution system through house transformer HT 1, and the second part from the stand-by transformer HT 2. To allow the circuit feeders and disconnecting switches of the sub-distribution systems to be designed for small rupturing capacities, the feeder cables were connected only over reactors to limit possible short circuit currents (main distribution rupturing capacity 200 MVA).

The switchgear used for the 380 V distribution is of the iron clad type. The sections serving the boilers are fed through 400 kVA transformers directly connected to sub-distribution group 1.

All the remaining iron clad sections are installed in duplicate and each is supplied by two separate cables from the open 380 V switching plant. This open switching installation is connected over 1,200 kVA transformers to the sub-distribution group 3 and is also split into two independent sections.

In the case of the boilers, duplication of the 380 V supply could be dispensed with as, in the event of a failure of the 6,000 V supply, operation of the boiler had to be discontinued in any case.

To keep the connexion between the 110 kV outdoor sub-station and the 110/6 kV house transformers as short as possible, the latter were installed in one line with the main generator transformers, and not close to the house supply station. This house supply station, situated between the coal bunker and the coal storage ground, contains all the main and sub-distribution gear, the 6/0·38 kV transformers and the open 380 V feeders.

The switch-house is a three-storey building. The third floor houses, in the space between the two chimneys of each half-station, the rather extensive switchgear, transformers, etc., for the electro-filters. The remaining space on this floor is used for offices, etc. The second floor houses the 6 kV main distribution gear, whilst the impedance coils and all the 6 kV sub-distribution gear are installed directly below on the

first floor. The 6/0·38 kV transformers and all the open 380 V distribution gear are installed on the ground floor.

As the flue gases flow into the chimney only above the switch-house, the lower part of the smoke stack has been designed as a staircase. As this part may also be used for the transport of switchgear, it was not necessary to provide special openings in the wall for assembly purposes.

GENERAL LAY-OUT OF THE STATION.

The decision to instal only two boilers of very high capacity for each generating group favoured a very compact general lay-out. There is one main operating floor, and the floor of the turbine house and the boiler room operating floor are on the same level. Only the main electric control room is on a different level, i.e. 1 metre higher.

HOUSE SUPPLY STATION.

This building is divided into compartments by the chimneys. Full use was made of this fact for air raid precautions. The blowers are installed 23 m above ground on the roof of this building, the layout of which was also influenced by the inclined conveyors which lead from the coal storage ground to the bunkers and cut right across the building.

There are two chimneys of 5 m internal diameter at the top for each half-station (4 boilers). The height of the chimneys is 100 m if the station fires brown coal containing sulphur and 60 m if it fires high grade hard coal.

COAL BUNKER.

The width of this building was determined by the electric precipitators installed on its roof, and its height by the required storage capacity. Above the bunkers are the belt conveyors for the coal. On the level of the main operating floor of the station (7·5 m), passages are provided through the bunkers leading from the switch house to the boiler house.

BOILER HOUSE.

The distance between the centre lines of two adjacent boilers is 18 m. The width of the boiler house was limited to 24 m, so that with the boilers 20 m deep, the space available in front of the boilers is 2·5 m and at the back of the boilers 1·5 m. This made it possible to install the 4 coal mills either in one line in front of the boilers or one at each corner. The height of the boiler house is 33 m and is uniform for all stations.

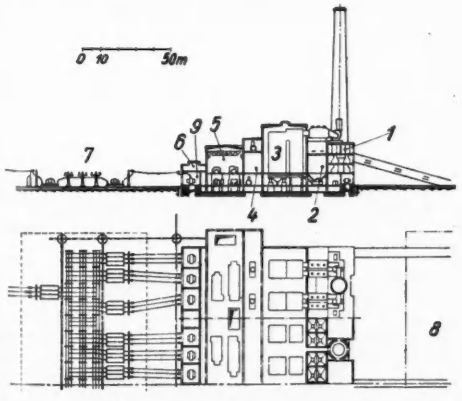


Fig. 3. **General lay-out of a 300 MW standard power station for brown coal.**

1. House supply switching station (chimneys incorporated in the building); 2. Coal bunker building; 3. Boiler house; 4. Central building (housing the steam control boards); 5. Machine house; 6. Main control room; 7. 110 kV outdoor switching station; 8. Coal storage ground; 9. Transformer house.

THE CENTRAL BUILDING.

As it had been decided, on principle, to erect one heavy structure on each side of the boiler house proper, the structural differences necessitated by the use of different fuels in the individual power stations could be confined to the bunker buildings.

Therefore, whether the station was designed for brown coal or hard coal firing, the central building is always free for the accommodation of the feed-water tanks (top), the Ruth's accumulators (bottom), the boiler control panel and various piping.

There is no central steam control room, but provisions were made for one to be built at a later date, should this be desirable. This could be done easily—by bringing the individual boiler control panels closer together, moving the turbine control panels from the turbines into the central building (boiler and turbine control panels are on the same level) and installing a control panel for the house steam consumption.

MACHINE HOUSE.

The width of this building is 20 m. The machines are installed in two rows, symmetrical with respect to the centre line of the complete station, but facing opposite directions (Fig. 3). The two half-stations were separated by a blast wall. Below the machine room floor are the boiler feed pumps and the feed-water preheating equipment. The machine house is equipped with two travelling cranes of 50 tons capacity each.

TRANSFORMER HOUSE AND MAIN CONTROL ROOM.

The generator and house transformers are designed for outdoor installation to allow alternatively for their installation near the power station as a part of an open-air installation, should this be required. Under normal conditions the transformers are installed in a transformer house forming a part of the power station block. The generator transformers are installed approximately opposite to their corresponding generators. The house transformers stand adjacent to the generator transformers further towards the centre of the station. The space in the centre of the transformer house, between the house transformers of each sub-station, is used as an ancillary room and for the stations' accumulator batteries.

The main control room of the complete station is housed in a special central structure above the transformers.

ANCILLARY PLANT.

Whilst the coal storage ground, the inclined conveyors, and the crushing plant, etc., are installed on the chimney-side of the power station, the 110 kV open-air switching station is built adjacent to the transformer house.

In addition, there are several buildings housing plant for the cooling water and general water supply and for feed-water treatment. This plant is designed to suit local conditions. In the case of fresh water cooling, the cooling water pump house contains screening equipment, etc., whilst, in the case of recirculation, towers had to be erected. The cooling towers are either for natural or for artificial draught and the owners of the station could choose between wooden or concrete towers, taking into account, in each case, the availability of materials.

The plant for the chemical feed-water treatment was standardized only on very broad lines because local

water conditions had to be taken into account in each individual case.

The overall dimensions of the six main structures of the complete power station block are :—

	Length m.	Width m.	Height m.	Capacity m^3
(1) House supply station and chimneys	152	14	23	48,950
(2) Bunkers and house	125	11	24	40,130
(3) Boiler house ..	152	24	33	119,400
(4) Central part ..	172	10	26	44,720
(5) Machine house ..	172	20	21	44,720
(6) Transformer station and control room	152	13	8	15,500
Therefore the maximum dimensions of the whole station building are	172	24	33	340,950

CONCLUSION.

It should be mentioned that the steel consumption for 300 MW installed capacity was 115 kg/kW.

Numerous investigations and calculations to find the most economic design for the whole station gave a specific consumption (in the case of natural circulation boilers and fresh water cooling) of about 2,530 kcal/kWh. However, these calculations could not be confirmed in practice, because, owing to war conditions, only one of these standard power stations actually went into operation. After all the stations had been designed and building was due to begin, materials could be allocated only for 5 out of the 13 stations planned, and on these, structural work was actually begun in spring, 1943. After one year's building, work had to be discontinued on four of these—although they were 60 per cent complete—so that eventually only one of the originally planned 13 stations was actually put into operation.

RUSSIA

The Insulation of District Heating Pipe Systems

By S. F. KOPYEV. (From *Promyshlennaya Energetika*, No. 7, 1946, pp. 3-6, 7 illustrations.)

THE condition and quality of insulation has a decisive influence on the economics of district heating schemes. One need only mention that in a highly developed network the losses will be from 5 to 8 per cent even with effective insulation, whilst costs, inclusive of outer walls, ducts, and other protective structures, amount to 25-50 per cent of the cost of the network.

Most heat distributing systems are laid underground, either without ducts or in ducts which do not allow ease of access and repair. It is, therefore, of primary importance that the means of insulation should be effective for a long period of service—say 25 to 30 years—and it should be much more carefully decided upon than for pipes laid in the open. The widespread idea that the surrounding soil itself is almost a good enough lagging material is quite erroneous. If insulation begins to break up the losses increase very sharply and can entirely nullify the thermal economies to be effected by adopting a district heating system. This is particularly true for small pipes, the insulation of which should, therefore, be chosen with great care—a point which is frequently overlooked. Poor insulation can raise heat losses to 30-50 per cent and thus doubly offset the fuel saving expected from the installation of a district heating scheme.

Intensive research into the condition of insulation used with existing heating schemes has shown that the " suspension " type of lagging, i.e., lagging wound on with wire or held on by netting, etc., is quite unsuitable. Actually it has been very popular, but experience has shown that in four or five years it breaks up completely and, because repairs are difficult, the pipes are left unprotected. Its adoption was a " crib " from overhead pipe practice without due consideration for the exceptional heat and humidity prevailing in underground ducts, which rusts wires, and rots binding material, while expansion and contraction cracks the mortar and cement. Some improvement can be effected, however, by using rustproof wire and by ventilating the ducts, but this type of insulation can never be a complete success and should be regarded as patently unsuitable for inaccessible locations.

Much better results are obtained with pipes which are solidly packed with milled peat or aero-concrete and it is a pity these materials have not been more widely used for heating networks.

A good construction not using walled ducts, which might be described as a semi-ducted layout, is one in which each pipe is surrounded by a thick cylindrical shell of insulation and is then rammed round with soil. Fig. 1 shows such a construction suitable for small pipes, where a solid cylindrical outer cover should be used and the intervening space should be filled with insulation. Fig. 2 shows the same principle suitable for larger pipes with the insulation made up of segments each segment having an outer cover of sheet steel, or cement, and a filling of cast, or rammed, insulating material.

In recent years there has been a tendency towards the use of completely ductless designs, with aero-concrete or peat filling. Aero-concrete in particular

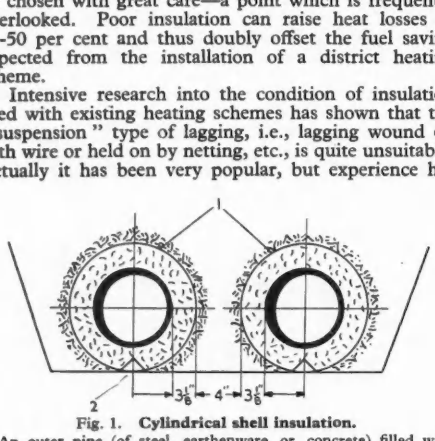


Fig. 1. **Cylindrical shell insulation.**
1. An outer pipe (of steel, earthenware or concrete) filled with insulation. ; 2. Drain.

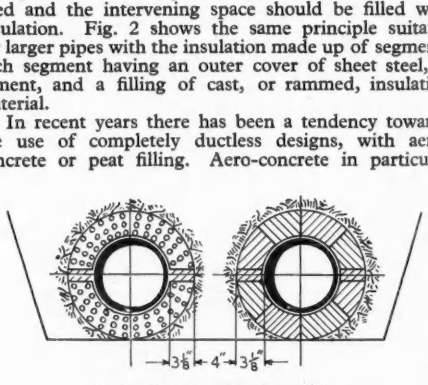


Fig. 2. **Segmental construction.**
Blocks of steel, earthenware or asbestos-cement filled with aero-concrete, diatomite, sovelite or other insulation.

is quite successful. It stands the test of time much better than the old-fashioned suspended insulation and entirely disproves the idea, common at one time, that it has a tendency to crumble into dust after a period.

The aero-concrete used is of 22-25 lb./cub. ft. density. It is sufficiently strong, and effectively protects pipes from corrosion on the outside whilst having a coefficient of thermal conductivity of less than 0·1 calories per metre per hour per deg. C. at a temperature of 50 deg. C.

Very surprisingly, ductless constructions are a success even with peat as the trench-filling medium, and this is in spite of the crudeness of the idea and the high moisture content of peat which generally remains fairly constant at 70-80 per cent. Experiments have shown that even after 8 or 10 years' service such networks possessed better insulating properties than the calculated performance of new diatomite or aero-concrete covered pipes laid in ducts. If the construction is ductless, peat can be used for temperatures up to 150 deg. C.

The outside surfaces of pipes rarely show signs of corrosion when peat filling is used. However, there has been one very striking exception to this rule. In the Moscow Meat Combine network the pipes under peat corroded right through and this, apparently, was due to a rare instance of peat containing highly corrosive elements.

A very good modern construction with prefabricated walls and a cast aero-concrete filling is shown in Fig. 3.

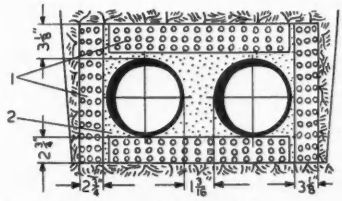


Fig. 3. **Prefabricated ducting of aero-concrete.**
1. Slabs of aero-concrete ; 2. Cast aero-concrete.

Similar designs in concrete or brick are satisfactory or peat can be substituted for the filling.

The insulation of un-ducted pipes often shows a very high moisture content even though the surrounding soil is not unduly moist. This is particularly the case with diatomite blocks. Nevertheless, attempts to keep moisture out by waterproofing must be regarded as ineffective and not worth attempting unless with some improved technique. It has been found that on the average "waterproofed" insulation does not keep drier than any other, chiefly because bitumen impregnated sack-cloth and other popular waterproofing materials are not sufficiently effective.

On the other hand, it is very important to keep underground springs and flood-water out of pipe trenches, because they reduce the effectiveness of insulation considerably and have occasionally been the cause of unfair criticism of the ductless construction. In fact they are even more harmful to pipes which are laid in ducts, and insulation in such cases can crumble away within a year.

The choice of insulating material has often been very unfortunate. With or without ducts, slag and cinders, various powders, and organic matter subject to rotting, are all quite unsuitable. Broken bricks, builder's rubble, etc., are also ineffective. Peat-board around ducted pipes, as distinct from milled peat in unducted networks, is mechanically too weak, and is thermally ineffective in the presence of moisture whilst being liable to catch fire when dry.

On the basis of these observations it is recommended that much greater attention should be given to the question of heat losses and the use of insulating materials than has been usual hitherto and in particular :—

(a) Suspension types of insulation with iron wire binding should never be permitted in inaccessible ducts. If it is so used, only copper or other rustless material can be accepted as binding material and this should preferably be in the form of continuous sheaths or netting. If wire must be used it should be at least one-twelfth of an inch in diameter and rustless.
(b) If the suspension type of insulation is adopted, it is best to use inorganic materials which can be wound on, i.e., slag wool in sheet form, or to enclose loose insulating materials in a strong sheath. Slag wool, sovelite and asbothermite are suitable.
(c) The use of the suspension type of insulation should be restricted to junction chambers and other locations where it is unavoidable.
(d) For all general purposes pipes should be laid either without ducts or in ducts which are entirely filled with packing. In such cases the insulation can be loose, tightly rammed, cast or prefabricated-segmental, and suitable materials are as listed before, plus peat and aero-concrete.
(e) To minimize heat losses, pipes should be laid as near each other as possible, even within an inch of each other, without any regard for the space requirements of valves and other fittings which have flanges. Spacing can be increased locally where required.

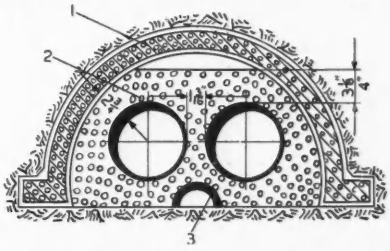


Fig. 4. **Vaulted duct with cast or rammed insulation.**
1. Reinforced concrete shell ; 2. Aero-concrete or rammed fibrous insulation ; 3. Drain.

(f) The use of cast or rammed lagging as in Fig. 4 will greatly reduce the size and cost of ducts.
(g) Rectangular ducts can, with advantage, be made of prefabricated hollow blocks filled with insulation and the roof should be of reinforced concrete (see Fig. 5).

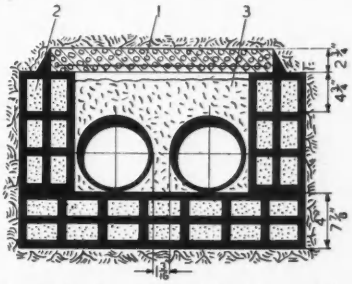


Fig. 5. **Prefabricated hollow block construction.**
1. Reinforced concrete slab ; 2. Hollow blocks filled with insulation ; 3. Rammed insulation.

(h) Cinders, crushed slag, rubble, and all materials subject to rotting, should be definitely barred as being ineffective and regulations should be drawn up prohibiting the use of combustible material in ducts, even under fireproof sheathing.
(j) Local materials should be used as much as possible for insulation and local production of the necessary blocks and segments should be developed to reduce transport charges.

RUSSIA

Investigation of an Experimental Mercury Boiler of 10 tons per hour Generating Capacity

By A. N. Loshkin. (From *Sovetskoe Kotloturbostroenie*, No. 6, 1946, pp. 1-10, 11 illustrations.)

The experimental investigation of mercury boilers in the Soviet Union dates back to 1937-1939 when, after a number of preliminary tests, a pilot plant of this type was erected at Leningrad for the purpose of studying the performance of the component parts of this type of plant. This pilot plant was brought into operation early in 1940 and was in service until June 1941 when war time exigencies enforced its shutdown after some 2000 hours of operation.

A diagrammatic representation of the installation is given in Fig. 1 which includes the main and the auxiliary plant as well as the piping systems carrying mercury vapour, liquid mercury, steam and water respectively. The chief component part of the installation is the mercury vapour generator with natural circulation; its capacity is 10 tons of mercury vapour per hour at a pressure of 10 atmospheres absolute corresponding to a mercury vapour temperature of 515 deg. C. The salient features of the mercury boiler are shown in Fig. 2 where it will be noted that the single drum boiler comprises two independent circulatory systems, namely the radiant wall tubing and the radiant screen tubing. The flame-exposed tubes are made of 18 per cent Cr, 8 per cent Ni steel, stabilized with Titanium, whilst all other heating surfaces are made of low-carbon steel tubing. The former material is electrically welded, and the latter is gas welded.

The convection bundle at the top forms an extension of the radiant tube systems and is passed by a mixture of mercury vapour and liquid mercury. This type of construction serves to keep the mercury content of the circuit to a minimum. The entire heating surface of the mercury vapour generator amounts to 26 sq. m. There is also an economizer which consists of a tube bundle placed on top of the convection section of the evaporating circuit. The oil fired furnace is equipped with two short-flame type Schuchau burners.

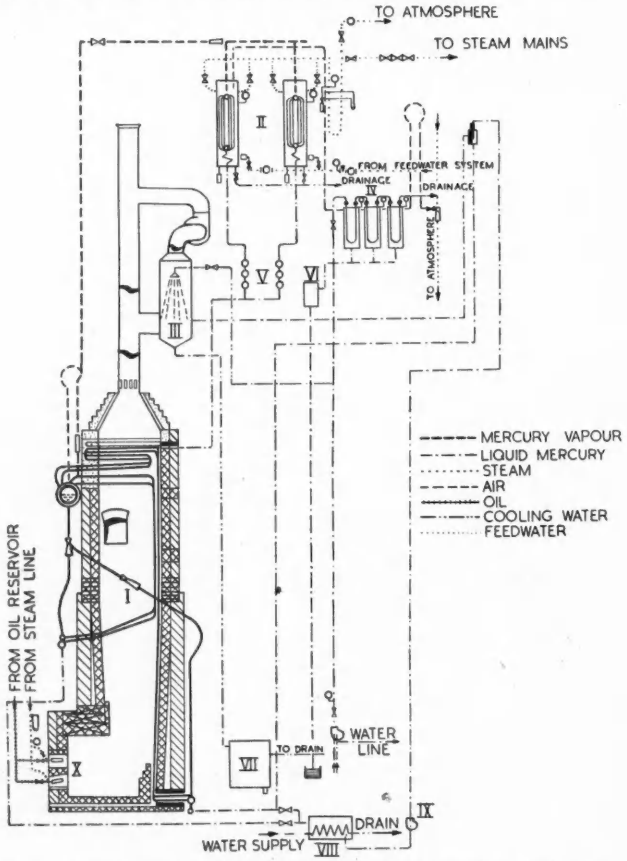


Fig. 1. **Mercury-water pilot plant at the experimental generating plant of the Central Boiler and Turbine Institute.**

(I) Experimental mercury boiler; (II) Condenser-evaporator; (III) Scrubber for cooling stack gas for the purpose of condensing mercury vapour in case of emergency; (IV) Ejector installation for producing vacuum; (V) Mercury sludge separator; (VI) Mercury collecting vessel; (VII) Collecting reservoir for scrubber; (VIII) Emergency collecting tank for mercury; (IX) Gear type mercury pump; (X) Oil burners.

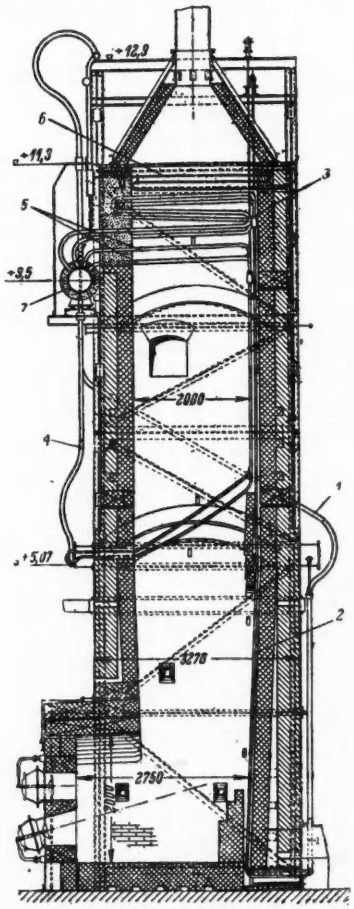


Fig. 2. **Mercury boiler with natural circulation.**

(1) Downcomers for wall tubing; (2) wall tubing; (3) convection section of wall tubing; (4) downcomers of furnace screen; (5) convection section of furnace screen; (6) mercury economizer; (7) boiler drum.

The mercury boiler was operated under the following conditions :

(*a*) Operation with water instead of mercury in order to establish comparative operating data for water and mercury.

(*b*) A first series of test runs with mercury at low pressures varying between 1·0 and 9·6 atmospheres at various firing rates.

(*c*) A second series of test runs with mercury pressures ranging from 7·0 to 13·5 atmospheres at firing rates from 50 to 80 per cent of normal.

(*d*) A third series of test runs at pressures from 9 to 13 atmospheres and firing rates from 75 to 100 per cent of normal.

The metal temperature of the boiler tubing was observed by means of thermocouples installed at all important points in the circuit.

The operating cycle of this semi-commercial experimental plant is the following : Mercury vapour is delivered from the mercury vapour generator through a throttle into the condenser-evaporator where condensation of the mercury vapour is effected by evaporating water at 12 atmospheres pressure. The mercury condensate passes, by gravity, from the mercury condenser hot-well through a sludge separator into the distributing header of the mercury economizer which is

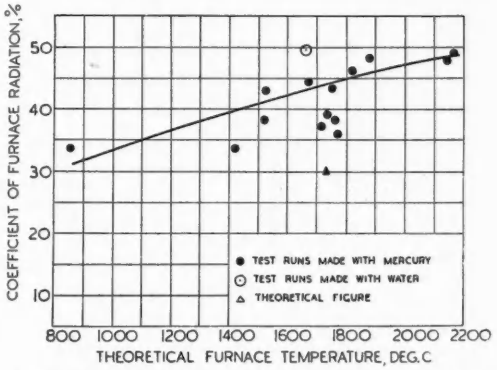


Fig. 3. **Relationship between coefficient of furnace radiation and theoretical furnace temperature.**

of the steaming type. From the latter the mercury passes through a separator and finally into the boiler drum. The mercury vapour released in the separator is passed into the collecting manifold of the mercury vapour mains. Filling of the boiler circuit with mercury is accomplished by means of a gear type pump. In the event of a fracture in the boiler tubing the mercury vapour will escape with the stack gases, and provision is made to recover the mercury by passing the flue gases through a scrubber in which condensation of the mercury vapour can be effected by a water spray. In addition, provision is also made for quickly draining the mercury from the system in case of emergency.

The plant has worked to full satisfaction both on water and on mercury ; with regard to the latter it has yielded valuable experimental data which will prove useful in connexion with the planning of further installations. A comparison of theoretical and experimental data showed the actual heat transfer in the furnace to be considerably in excess of theoretical values and to depend chiefly upon the theoretical furnace temperature (Fig. 3). Moreover, in the case of steam generation, the furnace heat transfer was found to be higher as compared with mercury vapour generation. This can be explained by the higher temperature of the heating surfaces when operating with mercury. As a result of the larger heat absorption in the furnace, the gas

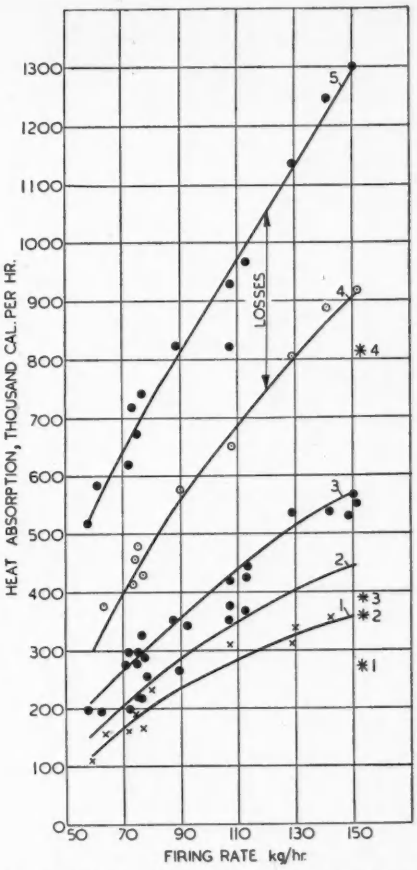


Fig. 4. **Influence of firing rate upon heat absorption in different parts of the heating surface.**

(1) Radiant heat absorbed by wall tubing ; (2) heat absorbed by radiation in wall tubing and by convection section of wall tubing ; (3) heat absorbed by wall tube system and by economizer ; (4) total heat absorbed by all heating surfaces ; (5) heat released in furnace ; (*) theoretical figures.

temperature at the furnace exit was below the estimated value.

When generating steam the boiler had an efficiency of 75 per cent as compared with a figure of 55-65 per cent when generating mercury vapour. In a commercial installation the efficiency of a mercury boiler will not, however, be less than that of a corresponding steam boiler, because the mercury boiler will be equipped with additional heating surfaces, i.e. with an air preheater, steam superheater, etc., which were not provided in the experimental installation under review.

In Fig. 4 is shown the influence of the firing rate upon the heat absorption of the individual component parts of the heat absorbing surface of the boiler when evaporating mercury.

Experimental data concerning the circulation of water and mercury respectively in the experimental boiler referred to are listed in Table I where the close agreement between theoretical and experimental data for the mercury boiler will be noted. The influence of the firing rate upon the circulation ratio K and upon the boiling level in the screen tubes both for water and mercury is charted in Fig. 5 which shows satisfactory agreement between theoretical and experimental results.

TABLE I. CIRCULATION CHARACTERISTICS OF EXPERIMENTAL BOILER WITH WATER AND MERCURY RESPECTIVELY.

Fuel burned	Drum pressure	Heat transferred	Wall tubing: Circulation of liquid		Wall tubing: Height of boiling point above inlet header, h_z		Wall tubing: Circulation factor, K		Furnace screen: Heat transferred	Furnace screen: Circulation of liquid		Furnace screen: Height of boiling point above inlet header, h_z		Furnace screen: Circulation factor, K	
			Test data	Theoretical data	Test	Theoretical	Test	Theoretical		Test data	Theoretical data	Test	Theoretical	Test	Theoretical
kg/hr	atmospheres	cal/hr	kg/hr	kg/hr	m	m	kg/k	kg/kg	cal/hr	kg/hr	kg/hr	m	m	kg/kg	kg/kg
Test data—water															
48·5	6	$173{\cdot}8.10^3$	$22{\cdot}2.10^3$	$18{\cdot}8.10^3$	2·2	2·1	74·3	63·0	130.10^3	$19{\cdot}6.10^3$	20.10^3	0·60	0·60	87·4	89·0
92·0	6	333.10^3	$26{\cdot}5.10^3$	$19{\cdot}3.10^3$	1·8	1·7	46·1	34·0	261.10^3	24.10^3	$22{\cdot}3.10^3$	0·45	0·45	55·0	51·0
Theoretical figures—mercury															
152	10	356.10^3	—	183.10^3	—	3·7	—	38·8	424.10^3	—	243.10^3	—	1·55	—	43·2
Test data—mercury															
150·7	11	443.10^3	185.10^3	194.10^3	3·6	3·7	31·1	32·6	336.10^3	220.10^3	252.10^3	1·40	1·58	48·5	55·5
141·3	10	444.10^3	174.10^3	192.10^3	3·3	3·5	29·0	32·0	323.10^3	203.10^3	267.10^3	0·82	0·94	46·8	62·0
112·5	9	289.10^3	154.10^3	195.10^3	3·0	4·1	39·5	50·0	279.10^3	156.10^3	224.10^3	1·55	2·00	41·4	59·3
107·6	12·13	225.10^3	147.10^3	—	4·3	—	49·0	—	222.10^3	162.10^3	—	1·52	—	54·6	—
112·3	11	362.10^3	202.10^3	191.10^3	3·9	3·8	41·2	39·0	291.10^3	196.10^3	—	1·55	—	49·6	—
108	10·14	351.10^3	$70{\cdot}8.10^3$	—	2·13	—	15·8	—	269.10^3	96.10^3	—	0·67	—	24·9	—
71·15	13·19	200.10^3	147.10^3	192.10^3	4·5	5·2	53·0	69·0	141.10^3	118.10^3	—	1·42	—	60·5	—

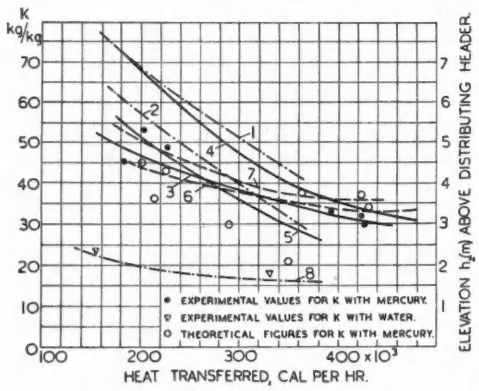

K kg/kg
ELEVATION h_z(m) ABOVE DISTRIBUTING HEADER.
HEAT TRANSFERRED, CAL PER HR.
400 x 10³
EXPERIMENTAL VALUES FOR K WITH MERCURY.
EXPERIMENTAL VALUES FOR K WITH WATER.
THEORETICAL FIGURES FOR K WITH MERCURY.

Fig. 5. **Influence of heating load upon circulation factor K and elevation h_z of boiling point above distributing header.**
(1) Test figures for K obtained with water; (2) theoretical figures for K computed for water; (3) test figures for K obtained with mercury; (4) theoretical figures for K computed for mercury for pressures from 6 to 14 atmospheres; (5) theoretical figures for K computed for mercury for pressures from 1·5 to 2·5 atmospheres; (6) test figures for h_z obtained with mercury; (7) theoretical figures for h_z computed for mercury; (8) theoretical figures for h_z computed for water.

The present article includes detailed tabulated data concerning the coefficient of heat transfer to boiling and non-boiling mercury as ascertained for the various component parts of the heat absorbing surface. Very high heat transfer coefficients were obtained for non-boiling mercury and these are in line with laboratory data. For boiling mercury, however, considerable variations in the magnitude of the heat transfer coefficient were observed. High figures were obtained for the vertically disposed parts of the heat absorbing surface, and in most of the tests high heat transfer coefficients were also recorded in the part of the boiler surface passed by vapour-liquid emulsion, particularly in the lower part of the surface. But lower heat transfer coefficients were registered for the upper part of the boiler surface carrying vapour-liquid emulsion. This points to a stratification of the steam of vapour-liquid mixture. Stratification also took place in the part of the screen carrying vapour-liquid emulsion, for which part much lower heat transfer coefficients were generally recorded. It appears that the differences in the heat transfer, for the parts of the screen and of the boiler tube bundle carrying vapour-liquid emulsion, are due to the conditions of flow because they influence the heat transfer at the inner tube surface. It could be shown that at or near points at which the direction of flow in the tube undergoes a change, the coefficient of heat transfer increases, whilst stratification diminishes accordingly.

Particular interest attaches to the fact that in the first test series at the commencement of the experimental work, high heat transfer coefficients were observed only in the vertically disposed parts of the heating surface; whilst in the second series of tests, greatly increased coefficients of heat transfer to the boiling mercury were registered also for the horizontal and the slanting parts of the heating surface, particularly along the lower part of the connexion tube bundle carrying vapour-liquid emulsion. In the third series of test runs a tendency towards an increase in the heat transfer coefficient became noticeable also with regard to the lower part of the screen. According to these tests the condition of the inner tube surface exerts a considerable influence upon the effective heat transfer from the tube wall to the boiling mercury. Mention should also be made of the fact that still higher coefficients for the heat transfer from the wall surface to the boiling mercury can be obtained by the employment of amalgams which cause a change in the wetting properties of mercury.

High heating loads were recorded during the tests, such as mean effective heat releases up to 200,000 cal. per cu.m. per hour, rising locally to 350,000-400,000 cal. per cu.m. per hour, while the mean effective heating load of the tube screen carrying vapour-liquid emulsion amounted to 50,000 cal. per sq.m. per hour, and that of the convection bundle to 15,000 cal. per sq.m. per hour. Even so it was found from thermocouple readings that the external tube metal temperature did not rise above 550 deg. C., and this despite the fact that the boiling point of the mercury lay between 515 and 525 deg. C. Only in the upper part of the tube bundle (5) (Fig. 2) local temperatures approaching 600 deg. C. were observed in straight portions of the tubes.

These results show that it is quite feasible to construct the heating surface of low alloyed tubing thus confirming the soundness of American practice in using Sicromo-5S steel containing 0·12 per cent C, 5·0 per cent Cr, 0·5 per cent Mo, and 1·5 per cent Si for mercury boiler construction.

During the period of operation only very slight defects were found, and these were mainly due to faulty welded joints. No difficulties with lighting up were experienced, sufficient boiler circulation establishing itself within 2 hours.

A Simple Method of Performance Calculation for Aircraft with Gas Turbine Power Plant

By P. MAEDER. (From *Flugwehr und Technik*, Vol. 9, No. 4, April, 1947, pp. 104-106, 4 illustrations.)

NOTATION.

a = Speed of sound, m. sec^{-1}
v = Air speed
$M = \frac{v}{a}$ = Mach number
ρ = Air density, kg. sec^2 m^{-4}
$\alpha = \frac{(\rho/_2\, a^2)_{H=0}}{(\rho/_2\, a^2)_H}$ = Characteristic for altitude
F = Wing area, m^2
β = Characteristic for throttling of power plant
γ = Characteristic for thrust decrease (function of altitude H)
φ = Inclination of flight path
R = Radius of curvature
H = altitude, m.
n = Coefficient of loading
c_a = Lift coefficient
c_w = Drag coefficient
A = Lift, kg.
W = Drag, kg.
S_H = Full load thrust at altitude H, kg. (function of M)
S_0 = Static thrust
G_0 = Unladen weight
$G = nG_0$ = Total weight
$(\rho/_2\, a^2)_{H=0}$ = 7140·25 (according to I.C.A.N.)

INTRODUCTION.

For flight without acceleration the forces acting on the aircraft must be in equilibrium. The equations for this condition are :

$$n \,.\, G_0 \,.\, \cos\varphi = A \quad .. \quad .. \quad .. \quad (1a)$$

$$\beta\, S_H = W + nG_0 \sin\varphi \quad .. \quad .. \quad (2a)$$

For level flight, $\varphi = 0$

$$n \,.\, G_0 = A = c_a \,.\, \rho/_2\, a^2 \,.\, M^2\, F \quad .. \quad (1)$$

$$\beta\, S_H = W = c_w \,.\, \rho/_2\, a^2 \,.\, M^2\, F \quad .. \quad (2)$$

In these equations the values c_a, c_w and M are unknown. As a third condition we have the polare of the aircraft which expresses the relation between c_w and c_a.

It will be shown in the present paper that if in the thrust-drag diagram instead of eqn. (1), as is at present customary, eqn. (2) is taken as the basis of the development, a considerable simplification of the performance calculation for turbine-powered aircraft is possible. This simplification is considerable when, as is often the case, the thrust decreases in proportion to $\rho/_2\, a^2$. If this is not so, a factor γ is introduced as defined by :—

$$\gamma = \frac{S_H}{S_{H=0}} \,.\, \frac{(\rho/_2\, a^2)_{H=0}}{(\rho/_2\, a^2)_H} = \frac{S_H}{S_{H=0}} \,.\, \alpha \quad .. \quad (3)$$

The procedure is briefly as follows :—

From eqn. (2) the drag coefficient c_w is calculated as a function of the Mach number. From the polare the co-ordinated values of c_a are obtained, and the lift is calculated. The points of intersection of the lift curve with the straight lines $n \,.\, G_0$ give the various flight conditions according to eqn. (1).

THE EQUATIONS.

From eqn. (3) : $\quad S_H = \gamma \,.\, S_{H=0} \,.\, \frac{1}{\alpha} = f_1(M)$

eqn. (2) : $\quad \beta \,.\, S_H = W = c_w \,.\, (\rho/_2\, a^2)_H\, M^2 \,.\, F$

By substituting $c_w = \frac{\beta \,.\, S_H}{(\rho/_2\, a^2)_H \,.\, M^2 \,.\, F} =$

$$= \beta \,.\, \gamma\, S_{H=0} \frac{1}{(\rho/_2\, a^2)_{H=0}} \,.\, \frac{1}{F \,.\, M^2} = f_2(M)$$

$$c_w = \beta \,.\, \gamma \,.\, 1{\cdot}4005 \,.\, 10^{-4} \frac{S_{H=0}}{F} \,.\, \frac{1}{M^2} = f_2(M) \quad .. \quad (I)$$

From the polare (Diagram 1) the co-ordinated values of c_a are read off. It is useful to redraw the polare so that c_w is plotted against the Mach number with c_a as parameter, and intersect these curves with the curves according to eqn. (I) which are plotted for various values of $\gamma \,.\, \beta$. (Diagram 2).

$$c_w \longrightarrow c_a = f_3(M) \quad .. \quad .. \quad (II)$$

From eqn. (1) we also have

$$n \,.\, G_0 = A = c_a\, \rho/_2\, a^2\, M^2\, F = c_a\, (\rho/_2\, a^2)_{H=0} \frac{1}{\alpha} M^2 \,.\, F$$

or $\quad \alpha \,.\, n = 7140{\cdot}25 \,.\, \frac{1}{G_0/F} \,.\, M^2 \,.\, c_a = f_4(M) \quad .. \quad (III)$

$\alpha \,.\, n$ is plotted against Mach number for various values of $\gamma \,.\, \beta$ as parameters (Diagram 3). In most cases

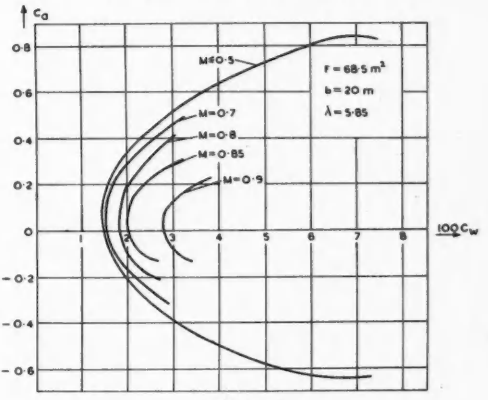


Diagram 1

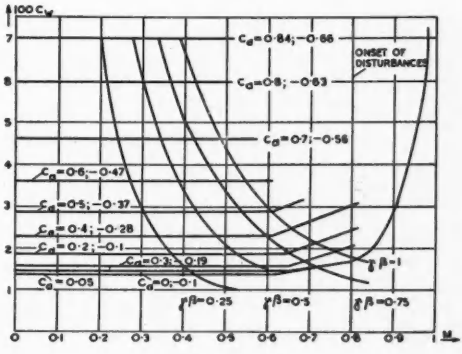


Diagram 2

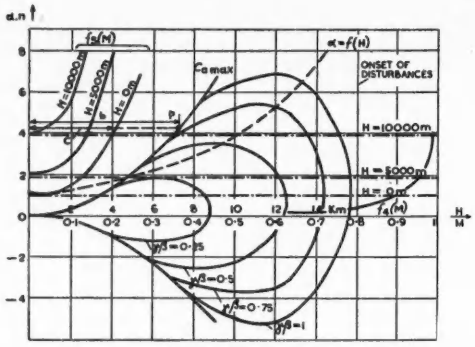


Diagram 3

γ is very nearly equal to unity so that only β need be varied. At low speeds c_w is greater than the c_w corresponding to $c_{a\,max}$ and throttling of the power plant is necessary.

Flight performances can be read from Diagram 3 as follows :

1. STRAIGHT LEVEL FLIGHT.

Here $n = \dfrac{G}{G_0}$ and at altitude H the values for minimum and maximum velocities can be read off directly under $\alpha \,.\, n$ for given values of γ and β.

2. CURVED LEVEL FLIGHT.

The radius of curvature can be written as :—

$$R = \frac{v^2}{g\sqrt{n^2-1}} = \frac{a^2}{g\sqrt{n^2-1}} \,.\, M^2$$

From this $$M = \sqrt{R \,.\, G}\ \sqrt[4]{n^2-1} \,.\, \frac{1}{a}$$

On the main diagram an auxiliary curve for a given value of α_k is to be drawn which is of the form

$$M_0 = \sqrt{K}\ \sqrt[4]{n^2-1} = f_5(M)$$

for which K is so selected that the curve comes near to the flight curve. n is the independent variable. The radius of curvature R for a given point P in the diagram at an altitude corresponding to α_k, is found through b and c (Diagram 3) as follows :

$$\frac{M}{M_0} = \frac{\sqrt{R.g}}{a\sqrt{K}} = \frac{b}{c} R = \frac{K}{g}\left(a\frac{b}{c}\right)^2$$

The minimum value for R can easily be obtained by varying the ratio $\dfrac{b}{c}$. Speed can be read off directly.

3. RATE OF CLIMB.

Here equations (1a) and (2a) are used. It can usually be shown that $\cos\varphi = 1$ is sufficiently accurate.

Also $M_{st} = M \,.\, \sin\varphi$ where M_{st} is the Mach number of the inclined path, and M that of the horizontal projection.

By substituting in eqn. (2a)

$$\beta_{st} \,.\, S_H = W + nG_0 \,.\, \frac{M_{st}}{M} \;;\; \beta_{st} = \text{throttle in climb}$$

In Diagram 3, for a given value of the parameter β

$$\beta \,.\, S_H = W$$

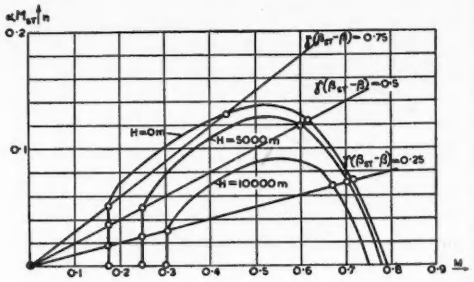


Diagram 4

For climb with a given β_{st} we have :

$$(\beta_{st} - \beta)\, S_H = nG_0 \,.\, \frac{M_{st}}{M}$$

or $$M_{st} = (\beta_{st} - \beta)\, \frac{S_H}{nG_0} \,.\, M$$

with S_H substituted from eqn. (3) :

$$M_{st} = (\beta_{st} - \beta)\, \frac{S_{H=0}}{nG_0} \,.\, \gamma\, \frac{1}{\alpha} \,.\, M$$

or $$\alpha \,.\, n \,.\, M_{st} = \gamma\,(\beta_{st} - \beta)\, \frac{S_{H=0}}{G_0} \,.\, M$$

Now an auxiliary diagram is plotted (Diagram 4) $n \,.\, \alpha \,.\, M_{st}$ against M with $\gamma\,(\beta_{st} - \beta)$ as parameter. Otherwise the diagram is self-explanatory. From the curves the rate of climb can easily be obtained and plotted against horizontal speed.

4. CEILING.

The ceiling can be obtained from the maximum value for $\alpha \,.\, n$ at $n = \dfrac{G}{G_0}$

5. DIVING SPEED (UNACCELERATED).

The diving speed as a function of $\alpha \,.\, n$ can be shown directly in the main diagram.

In a dive we have

$$c_a = 0 \qquad A = 0$$

$$W = n \,.\, G_0 = \rho/_2\, a^2\, M^2\, F\, c_w$$

$$= 7140{\cdot}25\, \frac{1}{\alpha}\, M^2\, F\, c_w$$

$$\alpha \,.\, n = 7140{\cdot}25\, \frac{1}{G_0/F}\, c_w \,.\, M^2 = f_6(M)$$

where c_w is to be taken at $c_a = 0$.

NOTES.

If for an approximate calculation the turbine-engine throttle curves are not known, the present method can be used best by taking $\gamma = 1$ and $S_{H=0} =$ constant for all Mach numbers. Turbine engines yield at $M = 0{\cdot}9$ approximately the static thrust, and thus the error is rather small. The only data then required are :—

the polare
Go/F = wing loading
S_0/G_0 = thrust per kg. weight at $H = 0$ m.

The original paper gives an example in calculating the performance of a four turbine-engine transport aircraft to which the diagrams shown relate. The paper is based on the author's dissertation at The Federal Technical College, Zurich.

Characteristics of Silver and Copper for use as Electrical Contacts

By B. W. Jones and L. L. Zickrick. (From *Product Engineering*, Vol. 18, No. 11, November, 1947, pp. 104-107, 8 illustrations.)

Silver and copper are increasingly used for electrical contacts because of better understanding of their unusual electrical and metallurgical characteristics.

Among these, for example, is the current-resistance characteristic of silver and copper sulphide. As shown in Figs. 1 and 2, the resistance of silver and copper sulphide films on their respective base metals varies in such a manner as to first increase and then decrease the current. In Fig. 1 the data were obtained on the normally closed circuit, across terminals, of the double break type of switchette, and is representative of a test of all of the contacts of five switchettes tested daily for nineteen days. The switchettes were exposed with the covers off and it took 0·3 volts initially to break down the insulation film. In Fig. 2, the current increased and decreased as shown by the arrow marking on each curve. These data are for No. 1 size pair of contacts and a pressure of approximately 25 grams. The resistance of both silver and copper sulphide decreases very materially as the current increases, and then remains substantially at this lower ohmic value when the current is subsequently decreased. However, the ohmic value of silver sulphide for a given current is lower than that of copper sulphide.

Silver, unlike copper, does not oxidize under ordinary conditions. But if the oxide film does appear on a contact surface, it will readily decompose and leave pure silver. This reaction is caused by the heat generated in the tips from the current passing across the contacts. Decomposition of silver oxide proceeds rapidly at an approximate temperature of 300 deg. C., and as the oxide is reduced the contact resistance is reduced appreciably.

Pure silver oxide as manufactured chemically is a very fine, soft, brownish-black powder somewhat like soot. Its electrical resistivity, like that of other metal oxides, is extremely high. Bars pressed from the pure oxide powder under heavy pressure give resistivity values ranging up to 45 meg-ohms per cu. cm. The idea that silver is a good contact metal because its oxide is a conductor is not substantiated by experimental data.

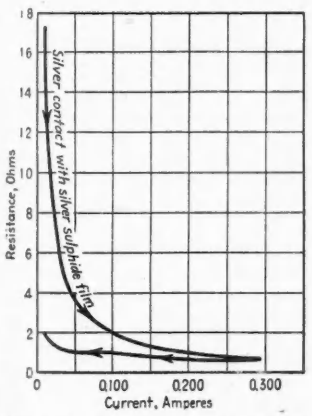


Fig. 1. **Current-resistance characteristics of fine silver contacts in a switchette aged in hydrogen sulphide for 13 days. Current is first increased from 10 to 300 milliamperes and then decreased over the same range of current.**

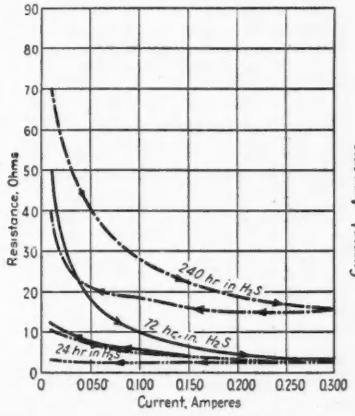


Fig. 2. **Current-resistance characteristics of copper contacts aged in hydrogen sulphide for different periods and tested on a pressure block at different current values. Contact pressure was one ounce throughout the tests.**

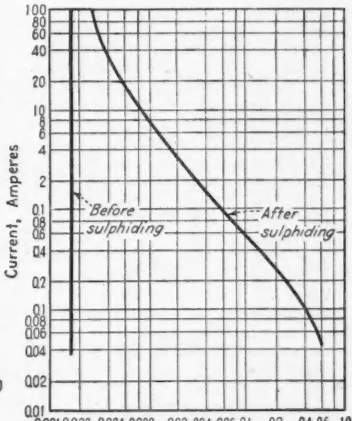


Fig. 3. **Resistance versus current characteristic for silver. Contact size No. 2 in sample switch was aged in a strong sulphiding atmosphere for 48 hours to show relative change involved.**

The same characteristic of silver where the current is increasing from 0·5 to 100 amp is shown in Fig. 3. But if the contacts are opened after the above changes in resistance have occurred as a result of the different currents and then reclosed, the same change from high to low ohms will occur because of the same current change.

Unlike copper sulphide, this reduction in the resistance of silver sulphide is a stable reduction. Possibly this unusual resistance effect of silver sulphide is caused by some of its little understood composition properties, especially those of a thin film. For example, it is known that silver sulphide changes in electrical resistance at a remarkable rate with only a relatively small change in temperature. At 173 deg. C. the resistivity is of the order of one-thousandth of what it is at room temperature, and at this temperature the form changes from the beta to the alpha form of much lower resistivity.

Silver sulphide is considerably softer and more plastic than similar tarnish films on base metals, being of the order of lead. Its softness helps make it easy to remove from any abrading or sliding action.

But pure silver with the surface in the proper condition is readily oxidized by ozone, O_3. The oxidation is instantaneous and the resulting film appears bluish black, smooth, and is at first extremely adherent. On thin silver strips the film is quite tenacious. At 400 deg. C. one or two minutes are required for complete decomposition to restore the silver to its original bright state. On contacts used where high voltages are involved, and especially if a glow discharge occurs, there may be sufficient ozone generated to "tarnish" the surfaces of silver tips.

Therefore neither the sulphide nor oxide of silver appreciably impairs silver as a good contact material. Tests have shown that 10 volts or even less, will generally puncture the sulphide surface films that form on silver contacts. But copper behaves differently. Copper

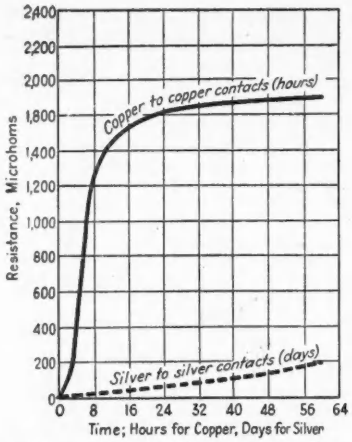


Fig. 4. **Contact resistance of copper and silver contacts when held at 20 lb. per sq. in. pressure. Contact faces kept apart while in an 85 deg. C. oven and contact resistance periodically measured.**

oxidizes rapidly, as shown in Fig. 4, especially at elevated temperatures. The copper oxides CuO and Cu_2O are not reduced by heat. On the contrary these films increase with temperature, thereby causing the contact to increase in temperature and thus creating a cumulative condition. This resistance can increase to such a degree that it will insulate the contacts against voltage as high as 125 or 250 volts.

When copper contacts are bolted together under high pressure, there is no increase in contact resistance because the two mating surfaces cannot oxidize.

The welding characteristics of contact materials can be determined by " Tentative Method for Life Test of Electrical Contact Materials," American Society for Testing Materials, Designation B 182-43T. The testing machine has three pairs of contacts, each of which make and break a 110-volt a.c. load once per second. The contacts are $^1/_4$ in. in diameter, the closing force is 100 grams and the opening force is 75 grams. The value of the current that causes the contacts to weld under these conditions is determined for each material.

One hundred thousand operations per pair of contacts are made for each condition of load and generally there are three or four conditions for each material. From these 100,000 or more makes and breaks, four significant characteristics are checked :

1. The " no-weld " current rating. This is the value of current that will just keep from welding any one contact material during 100,000 operations.

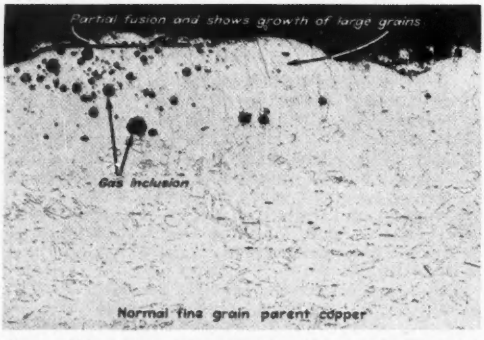


Fig. 5. **Effect of excessive local heating on copper contact tip of d.c. controller operating on 140 amp., 250 volts, inductive load ; 125,000 operations, 20 per minute.**

2. The average strength of the welds at a current near the no-weld current.
3. The loss of weight of each material when making 100,000 operations at or near the no-weld current.
4. The relative energy of the arcs of different materials. This is reflected in an approximate manner by the temperature attained by the contact tips.

When silver contacts are used the machine can run 100,000 operations making and breaking 24 amp. at 110 volts, 60 cycles, without any welding of the contacts. With copper contacts this current will cause welding. Also the arcing at the contacts will result in sufficient oxidation to insulate the tips and cause open circuit.

Nickel of higher specific resistance can make and break a maximum of only approximately 6 amp. without welding.

Test results for the no-weld ratings of several contact materials are shown in Table I.

TABLE I.

NO-WELD RATINGS OF DIFFERENT CONTACT MATERIALS.

Material.	No-Weld Current, amp.
Tungsten	35
60 Molybdenum-40 Silver	26
Silver	24
90 Silver-10 Iron	23
85 Silver-15 Cadmium	21
Nickel	6
75 Silver-25 Zinc	4

Copper : Oxidation causes open circuit.

It is interesting that silver is one of the lesser weldable materials on low currents of the order of 25 amp., but is one of the more easily weldable contact materials on the higher currents such as several hundred amperes. One explanation is that its high conductivity of heat makes it difficult to raise any appreciable amount of the surface metal to the melting point with a low current. Since the specific heat of silver is only about half that of copper, and it is in the low range for the contact metals, its high conductivity does not compensate for its low specific heat when carrying the higher currents.

In general it is believed that the four important factors affecting the tendency of a metal to weld are : (1) Specific resistance ; (2) specific heat and thermal conductivity ; (3) melting point ; (4) oxidation resistance.

ARCING CHARACTERISTICS.

If 25, 50 and 100 amp. direct current are permitted to arc between copper contacts that are separated approximately 100 mils or 0·100 in. between tips, the initial value of voltage that will appear as the contacts begin to separate will be 12, 13, and 14 volts respectively. The voltage for silver will be 12, for all three. The voltage reached at the end of the 100 mils travel will be

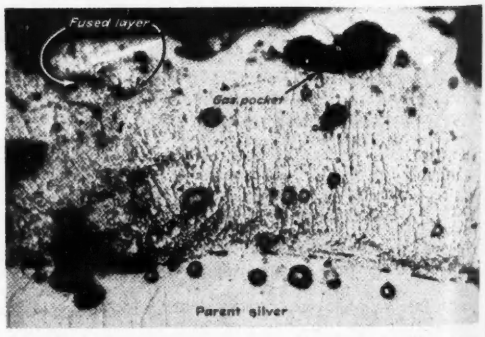


Fig. 6. **Photomicrograph of fused layer on face of silver contact, operated short time on currents varying from 220 to 380 amp., 200 volts, direct current.**

27, 28, and 29 volts for copper, and 32, 33, and 34 volts for silver. The time duration will be in the order of several milli-seconds. This gives an indication of the order of magnitude of energy that appears close to the surface of the contacts when an arc is drawn, how much metal is melted, and how much is vaporized if all the energy remained at the spot where the arc is struck.

High temperature on the surface of any cold metal is rapidly lowered by the surrounding cold metal. But the thermal conductivity, the specific heat, the melting point, and boiling point, together with the heat of fusion and the heat of vaporization are all factors that produce a given effect.

If these two metals are permitted to arc during one half cycle of time and the value of voltage required to re-establish the current for the second half cycle is then ascertained, the result will be a measure of the arc extinguishing characteristic of these two metals under this condition. With a reactive load of 50 per cent power factor and an impedance of approximately 6 ohms, copper begins to re-establish on 320 root-mean-square volts while silver required 440 volts on the same contactor. This shows that silver has the more desirable characteristic in this respect.

EFFECT OF HEAVY CURRENT.

The crystal structure and condition of the face of a contact tip may become altered after operating under heavy load conditions. A photomicrograph showing a simple condition of a copper tip whose surface has been altered from that of the underlying metal is shown in Fig. 5. It shows that local surface heating caused the formation of excessively large grains, partial fusion, and formation of some gas inclusions. This altered structure extends to a depth of about 10 mils, or 0·010 in. Continued operation of copper tips under such conditions also causes the formation and growth of copper oxide layers, occasionally as much as several mils thick.

Oil operation produces a rate of wear about 40 to 50 times that of similar tips operated in air. Excessive local temperature causes partial fusion with formation of considerable porosity from gas cavities. These are formed by (1) absorption of gas from the arced oil at high temperature, followed by (2) ejection from solution during the extremely rapid drop in temperature after the current is interrupted. Subsequent operations with instantaneous high surface temperature easily tear this weakened structure, possibly aided by sudden expansion of gas contained and trapped in the tip surface.

The deposit of a fused layer on the surface of a silver tip operated at about 300 amp direct current is shown in Fig. 6. This layer of 0·002 in. thick metal was molten and then resolidified on the silver surface. Such a deposited layer may become the contact surface during subsequent operations, giving poor contact, causing higher temperatures than normal, and result in an increased rate of wear.

Solder and soldering flux are used commonly for soldering or brazing contacts to their supports. During this process the flux or solder may get on the surface of the contacts.

It has been found that this solder contamination will cause failure to make circuit and may also cause the contacts to weld more readily than will the pure silver or copper. Therefore, care and caution should be used in design to prevent such contamination. When practicable, the use of soldering operations should be eliminated.

HOLLAND

Fundamentals for the Development of the Philips Air Engine

By H. DE BREY, H. RINIA and F. L. VAN WEENEN. (From *Philips Technical Review*, Vol. 9, No. 4, 1947, pp. 97-104, 5 illustrations.)

DURING recent years extensive theoretical and experimental investigations of the hot-air engine process were carried out in the Philips Laboratories, and it was found that this process can be employed to much greater advantage than hitherto, provided that in the construction of such engine modern knowledge of heat transfer, flow resistance, etc., is utilized to the full. It has been found possible to build air engines having the same efficiency as comparable ordinary internal combustion engines, and developing a higher power than the latter per unit of cylinder volume or engine weight.

In an air engine of this type a certain quantity of air (or some other working medium, such as hydrogen, helium, argon) at high temperature is allowed to expand in a cylinder—the "hot space"—where it performs mechanical work by moving a piston. In another cylinder—the "cold space"—the expanded air is cooled and compressed to its original volume by the action of a piston ; it is then reheated to its original high temperature. The cycle then begins anew. The compression of the air requires mechanical work ; but as this compression takes place at low temperature, and therefore, at low pressure, the work required is less than that performed by the expansion of the air from high temperature and pressure. The engine thus produces an excess of work.

A greatly simplified diagram of an air engine is given in Fig. 1. Here the movement of the air from the hot to the cold space and vice versa is accomplished by two pistons having approximately sinusoidal motion, with a phase difference of about 90 degrees. Since

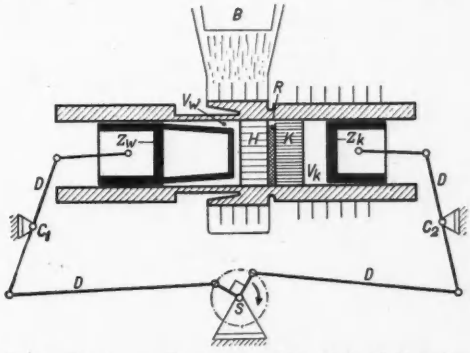


Fig. 1. **Diagrammatic representation of the design of an air engine.**

V_w hot chamber, V_k cold chamber, with the corresponding pistons Z_w and Z_k. B burner, H heater, R regenerator, K cooler, S crankshaft, D connecting rods, C_1, C_2 fixed pivots.

the four different stages of the process, i.e., expansion, cooling, compression, heating, cannot be entirely separated, they partially overlap. In spite of this the machine functions as an engine, provided the volume changes of the hot space are advanced in phase with respect to those in the cold space.

The so-called regenerator R shown in Fig. 1 serves to store the heat given off by the air after the expansion

when passing to the cold space. After compression when being returned to the hot space the air again passes through the regenerator and absorbs the heat stored in the latter.

The investigations made had a two-fold object, namely (a) to improve the efficiency and (b) to increase the specific power, i.e., the power delivered to the main shaft divided by the swept volume. For the sake of greater clarity the specific power will be considered first. The specific power is the product of the number of revolutions and the mean effective pressure p_m.

INCREASE OF THE SPECIFIC POWER.

All the old air engines worked with a maximum pressure of only a few atmospheres, and the lowest pressure was about one atmosphere. Therefore the mean effective pressure was not usually higher than about 0·6 atmospheres. The fact that higher pressures were not used was due mainly to the lack of suitable materials. Thanks to the employment of modern materials of high creep strength at high temperature, it has been possible to increase the maximum pressure to approximately the same level as in internal combustion engines, i.e., to about 50 atm. The minimum pressure is then about 22 atm and the mean effective pressure p_m is about 14 atm. This is more than twice as high as in ordinary internal combustion engines in which, as a result of the less favourable shape of the indicator diagram, a value of p_m of the order of 6 atm. is obtained. These conditions are represented diagrammatically in Fig. 2.

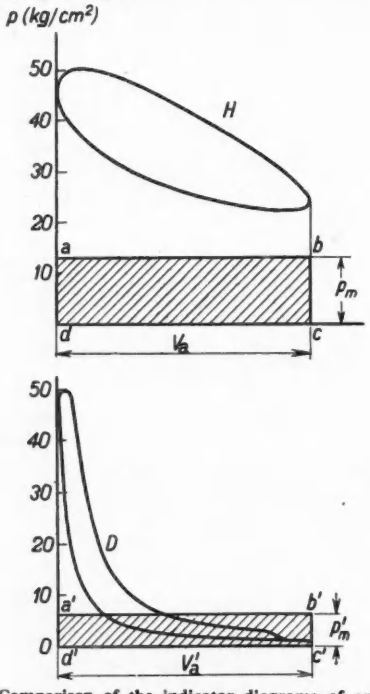


Fig. 2. Comparison of the indicator diagrams of an air engine (*H*) and a two-stroke Diesel engine (*D*). The swept volume V_a is assumed to be equal in both cases.

The engine speed is limited mainly by two factors. In the first place the piston speed, and thus the forces of inertia, of the moving parts increase with the engine speed. In the second place, a higher speed requires a more rapid flow of the working medium between the hot and the cold spaces, thereby not only increasing the frictional losses in heater, regenerator and cooler, but making it more difficult to obtain the required heat

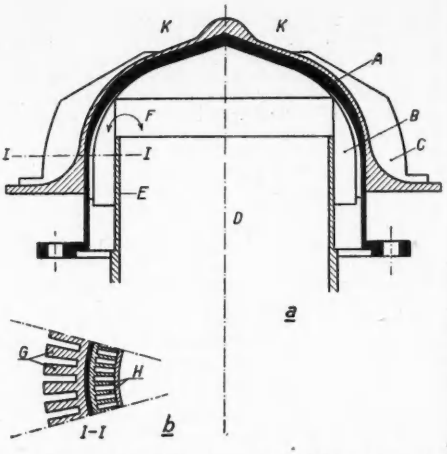


Fig. 3. Cross-section of the heater of a Philips air engine.

(*a*) vertical cross-section ; (*b*) part of horizontal cross-section at height *I-I*. *A* bonnet of heat-resisting steel to withstand the pressure of the working medium, *B* fins of aluminium bronze for the heat exchange with the working medium (see also at *H* in the horizontal cross-section), *C* fins of aluminium bronze for the heat exchange with the flame of the burner (see *G* in horizontal cross-section), *D* hot space, *E* wall of the hot space. The fuel is burnt at *K*. The flame is led through the slits between the fins *G*. These and, as a result of the good heat conduction, also the fins *H*, are thus heated to the required temperature. The heat exchange with the working medium takes place in the slits between the fins *H*. The working medium can enter or leave the hot space only *via* the paths indicated by the arrow *F* (the hot space is closed at the lower side by a piston not shown here).

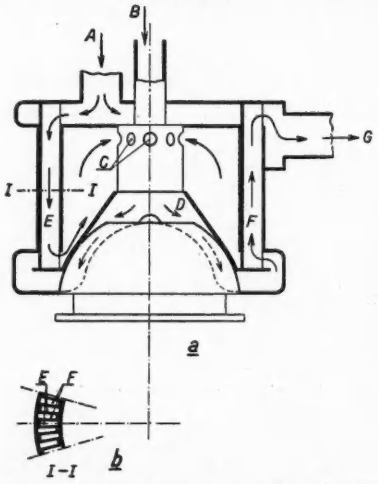


Fig. 4. Cross-section through the preheater of a Philips air engine.

(*a*) vertical cross-section ; (*b*) part of horizontal cross-section at height *I-I*. The air for combustion enters at *A*. It follows the path of the arrows, thereby passing through the channels *E* and entering the space *D* *via* the openings *C*. The fuel gas—which enters through *B*—is mixed with the air in *D*, where the combustion takes place. The heater (Fig. 3) along which the flame is led is indicated by dotted lines. The products of combustion are passed out *via* the channels *F* and the opening *G*. In the annular space, of which *E* and *F* represent a vertical cross-section, is a pleated collar (see also horizontal cross-section). In this lie the channels *E* and *F* alternately side by side.

transfer in these elements. On account of the novel design of these three elements, the problems of flow resistance and heat transfer no longer constitute obstacles to a considerable increase in engine speed. The piston speeds decrease with the working pressure and a given power can be obtained with a smaller swept volume. This makes it possible to raise the speed to 3000 r.p.m., or higher, which again leads to a considerable increase in specific power. Also the weight of the engine is much reduced.

IMPROVEMENT OF THE EFFICIENCY.

A special heater was developed to raise the air temperature to about 650 deg. C. at the entrance to the hot space. The design of the heater for a given application is shown in Fig. 3, where the large number of channels formed by internal fins will be noted. The outside of the heater is kept at the desired temperature by a burner.

The purpose of the regenerator is to store the heat given off as the working medium (air) passes from the hot to the cold space and to yield this heat again to the air when the movement is reversed. The importance attaching to the regenerator is clearly seen if it is realized that the ratio of the amount of heat stored in the regenerator and the amount of heat supplied by the heat per cycle is 3 or slightly higher. The working medium thus absorbs more than three times as much heat in the regenerator as in the heater.

Considering the requirements to be met by the regenerator, care must be taken in the first place to effect a sufficiently rapid heat exchange between regenerator and air. In the second place the regenerator must possess a large heat capacity. Also, the heat conductivity of the regenerator in the direction of air flow must be low, as otherwise a continuous flow of heat will occur from the heater to the cooler, which would mean a loss.

It has been found possible to construct regenerators which come very close to the ideal. Such regenerators consist of porous coils of thin metal wire giving regenerator efficiencies of 95 per cent and higher. It is a remarkable fact that such a coil of metal is capable of raising the air temperature from about 100 deg. C. to 600 deg. C. within 0·01 sec., or the reverse, which means that temperature gradients of several hundred degrees per centimetre in the direction of flow exist without appreciable loss of heat.

In the case of the Philips air engine, the heater has a temperature of more than 650 deg. C. and the flame and the products of combustion have a still higher temperature. If the exhaust gases are allowed to escape unused, a considerable amount of heat will be lost. This loss can be very much restricted by the use of a heat exchanger in which the exhaust gases give off their heat in counterflow to the combustion air. Such a preheater, for example, may have the shape of a pleated collar of heat resisting sheet metal, the exhaust gases being passed along one side of the pleats, while the combustion air flows along the other side. In this way a very intensive heat exchange is obtained and the exhaust losses can be restricted to about 30 per cent of the original value. A preheater for gaseous fuel and especially adapted to the air engine is shown in Fig. 4.

SWITZERLAND

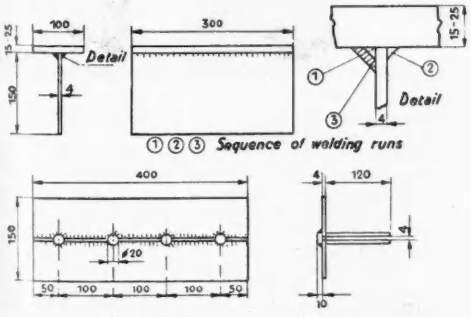
Testing of Electrically Welded Constructional Components of Aluminium Alloys

By L. HUGUENIN. (From *Schweizer Archiv*, Vol. 13, No. 7, July, 1947, pp. 202-210, 23 illustrations.)

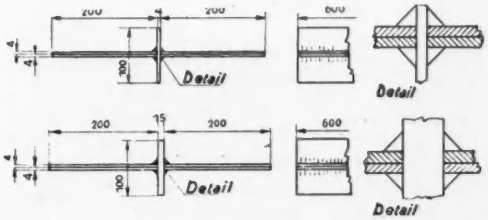
THE casting of intricate light alloy casings such as those for aircraft engines usually requires elaborate equipment and prolonged experiments before production can be started economically. If, at the beginning, production is limited to small numbers, the time and money required may be out of proportion with the size of the job.

It was proposed to investigate an actual example, namely, the production of the bottom part of a 12-cylinder aircraft engine casing and to find out whether in such cases the light alloy casting could be replaced by a welded fabrication. The experiments were confined to electric arc welding, as this appeared to be the most appropriate process, and were expected to provide data on the best type of parent material, the type and sizes of electrodes,* amperage, preheating temperature, design and sequence of welding operations, and on the maximum static and dynamic strength, as compared with castings.

*These aspects are not dealt with in detail in this abstract because materials and electrodes used all refer to Swiss Standards. Readers interested in the subject may obtain further details upon request.—Editor, E.D.



Figs. 1 and 2. Two welded specimens.



Figs. 3 and 4. Specimens with twin plates fillet-welded to a cross plate.

The welded specimens were prepared by a skilled welder, and uniform preheating over the full width was obtained by using a specially constructed device.

Before starting on the actual program of experiments the welder was given an opportunity to practice on smaller test-pieces and to try, at the same time, to ascertain the most suitable temperature for pre-heating. Three different types of light alloys were tested, using three types of electrodes.

PREHEATING TEMPERATURE, AMPERAGE, ELECTRODE DIAMETER AND POROSITY.

To clarify these conditions a series of 76 tests was carried out. The best temperatures for preheating were found to be between 250 and 300 deg. C., depending on the parent material ; at these temperatures welds were found to be practically non-porous and fairly uniform. 110 to 160 amps. were required, with 4 to 5 mm diameter electrodes. These were heat-treated, and substantially non-porous welds were thus obtained with a preheating temperature of only 100 deg. C. This procedure was abandoned, however, because of unsatisfactory penetration and the weld surface produced, which had grooves and overlappings owing to the high amperage used. Welding at so low a preheating temperature caused higher susceptibility to cracks at critical points.

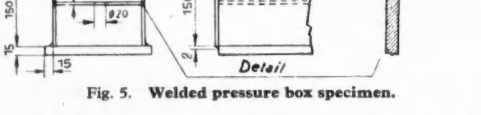


Fig. 5. **Welded pressure box specimen.**

Tests with specimens as shown in Figs. 1 and 2 resulted in the exclusion of one of the three parent materials and two of the three types of electrodes. Considerable difficulties were experienced in welding certain types of specimens. Those shown in Figs. 3 and 4 gave poor results when subjected to alternating tensile tests because of the internal slot between the twin plates which produced a kind of notch effect. The welding of rectangular boxes as shown in Fig. 5 presented no difficulties and they were found to be leak-proof with 14 atmospheres internal pressure. The total of materials used in these tests was approximately 1,300 electrodes and 200 kg. of light alloys.

ALTERNATING TENSILE STRENGTH.

Specimens were prepared from the pieces shown in Figs. 3 and 4 and one of each type was tested in the "as received" condition, and another of each type after normalizing. The upper load limits were 60, 40, 30, and 20 per cent of the static U.T.S. which had previously been ascertained.

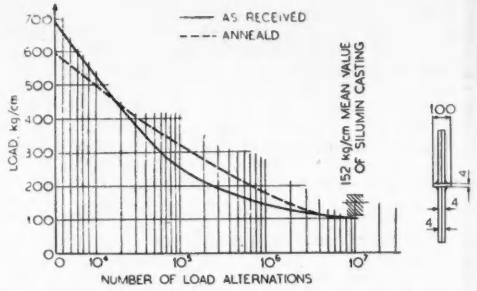


Fig. 6. **Wöhler curves for fatigue tests with specimens shown in Fig. 3, with 4 mm cross plates.**

Typical test results are given graphically in Figs. 6 and 7. Mean values for alternating tensile strength varied between 0·95 and 1·8 kg/mm² of the cross-sectional area, with 10^7 alternations. These low values are explained by the notch effect caused by the slot between the twin plates, and the result was the type of fracture shown in Figs. 8 and 9 which correspond to the test specimens illustrated in Figs. 3 and 4. The notch effect was successfully eliminated with specimens having the twin plates replaced by single plates. For two different alloys the values for alternating tensile strength with 10^7 load alternations were thus increased to 3·0 and 4·1 kg/mm², respectively, representing about 3 times the figures obtained with the twin plate specimens. The maximum value of 4·1 kg/mm² is well above the 2·24 to 3·50 kg/mm² alternating tensile strength of the Silumin castings normally used for these engine casings.

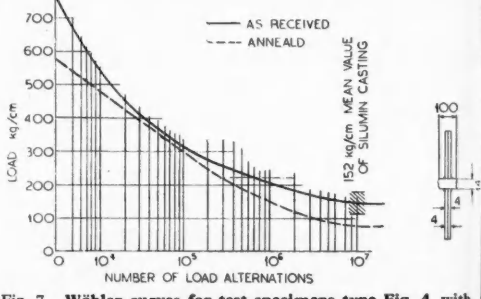


Fig. 7. **Wöhler curves for test specimens type Fig. 4, with 14 mm cross plates.**

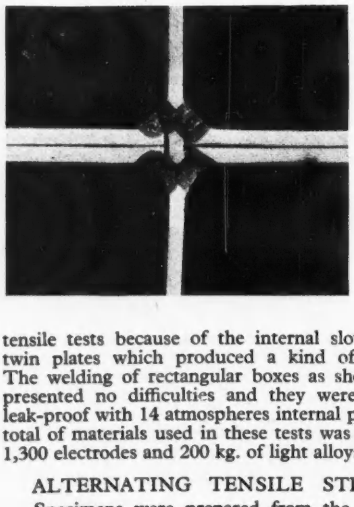
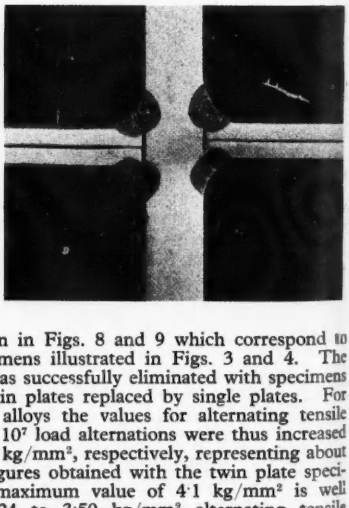


Fig. 8 (left). **Fatigue fracture of a specimen type Fig. 3, with 4 mm cross plate.**

Fig. 9 (right). **Fatigue failure of a specimen of type Fig. 4, with 14 mm cross plate.**



NEWS OF THE MONTH

Announcements in this section include News relating to British Firms, and on Equipment produced by British Manufacturers.
Available literature may be secured by addressing a request to the advertising department of "The Engineers' Digest," or by writing direct to the manufacturer and mentioning "The Engineers' Digest" as a source.

- PERSONAL
- NEW EQUIPMENT
- BOOKS AND CATALOGUES
- BUSINESS CHANGES
- NOTES

PERSONAL.

Mr. E. Aron has been appointed managing director of E. H. Jones (Machine Tools) Ltd. **Mr. E. J. M. Jones** has become deputy managing director of the company.

Sir George E. Bailey, M.I.Mech.E., M.I.E.E., relinquished his position as managing director on assuming the office of full-time deputy chairman of Associated Electrical Industries Ltd. **Dr. H. W. Hugh Warren, M.I.Mech.E., M.I.E.E.,** has been appointed managing director of the company.

Mr. E. H. Ball, M.I.E.E., has been appointed managing director of the British Thomson-Houston Co., Ltd.

Mr. W. B. Baxter has been appointed a director of the United Steel Companies Ltd.

Mr. H. L. Binning, A.M.I.C.E., A.M.I.Mech.E., of 6 Rossmore Avenue, Parkstone, Dorset, has been appointed to the Colonial Service as an Executive Engineer in the Gold Coast.

Mr. E. S. Booth, M.Eng. (L'pool), A.M.I.E.E., has been appointed City Electrical Engineer, Salford Corporation Electricity Supply.

Sir George Elliston, M.C., has been re-elected President of the National Smoke Abatement Society. **Sir Ernest Smith, C.B.E., D.Sc.,** has been re-elected honorary treasurer of the society.

Mr. C. L. G. Fairfield, M.A., A.M.I.Mech.E., A.M.I.E.E., has been made technical assistant to the directors of the Mullard Wireless Service Co., Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Mr. H. R. R. Farmer, G.I.Mech.E., of 12, Sandall Rise, Wheatley Hills, Doncaster, has been appointed assistant locomotive superintendent in the Railway Department of Nigeria.

Mr. G. W. Griffin, general works manager, has been appointed to the Board of Directors of Siemens Brothers & Co., Ltd.

Mr. H. S. Haslam has been appointed engineering director of English Clays Lovering Pochin & Co., Ltd., St. Austell, Cornwall.

Mr. P. E. Holden has been elected a director of the Projectile and Engineering Co., Ltd.

Mr. D. Digby Hawley, M.C., manager of the sales department; **Mr. Alec Jack, B.Met.,** recently appointed London manager, **Dr. J. R. Rait, A.R.T.C.,** research controller; and **Mr. F. Cousans F.I.M.,** foundry controller, have been appointed local directors of Hadfields Ltd., East Hecla Works, Sheffield 9.

Mr. David Jackson has been appointed joint managing director of Mavor & Coulson Ltd., with special control of all technical and production matters. Mr. J. B. Mavor remains chairman of the company.

Mr. C. J. Lake has been appointed chairman of Lake & Elliot Ltd.

Mr. I. Manning has been appointed assistant technical officer (metallurgy), and **Mr. P. A. Morgan** has been attached to the research department of the Metals Division, Birmingham, of the Imperial Chemical Industries Ltd.

Mr. F. A. Martin has been elected chairman and **Mr. F. W. Rowe,** vice-chairman of the British Steel Founders' Association.

Mr. C. G. McAuliffe has been appointed head of the sales, research and statistical section and **Mr. E. G. Fielding** has been appointed publicity officer of The British Aluminium Co., Ltd.

Mr. D. McLeod, of 116b, Adelaide Road, London, N.W.3, has been appointed as an electrical engineer in the Public Works Department of North Borneo.

Mr. Patrick G. Murphy has been appointed chief engineer in charge of all technical departments of the Electricity Supply Board, Dublin, Eire.

Captain R. G. Murray, C.B.E., has been appointed director of Aircraft Maintenance and Repair at the Admiralty.

Mr. Godfrey Oakey and **Mr. J. Graham Oakey** have been elected directors of John Oakey & Sons Ltd.

Mr. D. P. Oliver has been appointed deputy chairman designate of the Merseyside and North Wales Electricity Board. **Mr. R. A. S. Thwaites, M.I.C.E., M.I.Mech.E., M.I.E.E.,** manager of the Manchester Corporation Electricity Department, has been appointed deputy chairman designate of the North Western Area Board.

Sir **Frederick Handley Page, C.B.E., F.R.Ae.S.,** has been appointed to represent the Royal Aeronautical Society on the General Board of the National Physical Laboratory.

Mr. W. L. Patterson has been appointed manager of the Manchester office of C. A. Parsons & Co., Ltd. Mr. F. W. Waddingham retains his position as district engineer at the Manchester office.

Mr. J. G. W. Pawlyn, of Ransomes, Sims & Jefferies Ltd., has been elected to the council of the British Engineers' Association.

Mr. D. Rebbeck, M.A., M.Sc., has been elected President of the Belfast Association of Engineers.

Mr. H. V. Redshaw has been appointed managing director of the Crane Foundry Co., Ltd., Wolverhampton.

Mr. Richard Sellers Reed, M.Sc. (Manch.), M.I.Mech.E., has been appointed Principal of the Gloucester Technical College.

Mr. R. M. T. Richards has been appointed Deputy Chief Regional Officer, British Railways, Southern Region.

Mr. C. F. Russell has been appointed Chairman of the Aero Piston Ring Co., Ltd., and **Mr. L. H. Maidman** and **Mr. L. P. Gibson** of Specialloid Ltd., have joined the Board of the Aero Piston Ring Co., Ltd.

Mr. A. F. Scargill, A.M.I.E.E., has been appointed Borough Electrical Engineer to the Batley Corporation Electricity Department.

Mr. G. H. Sheldon has been appointed managing director of Walker Bros. (Wigan) Ltd.

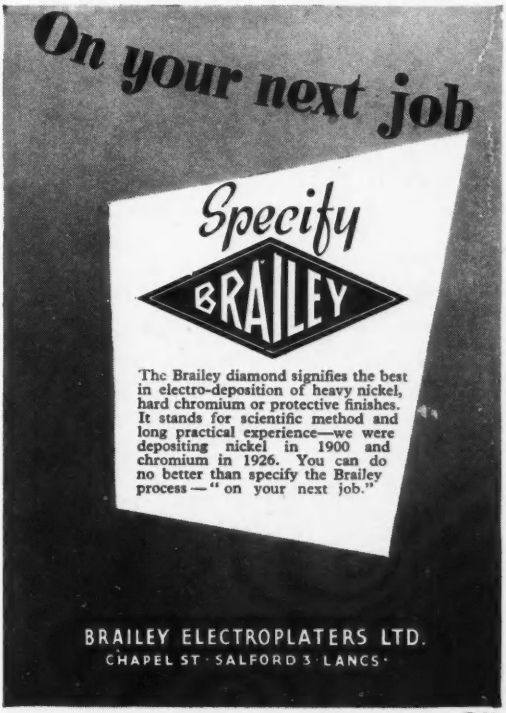
Mr. G. F. Sinclair, M.I.E.E., A.M.I.Mech.E., has been appointed chief technical planning and supplies officer, and **Mr. F. G. Maxwell** has been appointed operating manager (railways) of the London Transport Executive, 55, Broadway, London, S.W.1.

Mr. L. C. Steinle has been elected chairman, and **Mr. J. Mackenzie** and **Mr. H. R. Scott** have been appointed joint managing directors of the Hanwell Engineering Co., Ltd., Northampton. Mr. Mackenzie has been for many years general manager of the Company.

Mr. W. Szwander, Dipl. Ing., M.I.E.E., has been appointed chief technical assistant in the Belfast Electricity Department.

Mr. Sydney E. Taylor, D.Sc., M.A. (Cantab.), has been elected President of the Institution of Mining and Metallurgy.

Sir Henry Tizard, K.C.B., A.F.C., F.R.S., has been appointed chairman of the new Committee on Industrial Productivity set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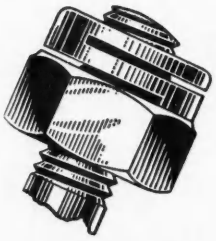

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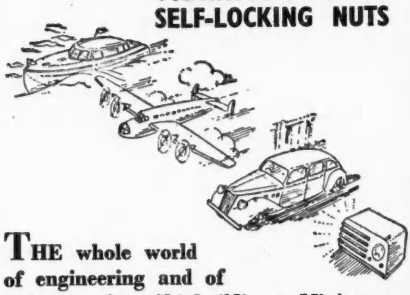

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up by H.M. Government to supplement the work of the Advisory Council on Scientific Policy. Other members of the new Committee include **Sir Edward Appleton** and **Sir Claude Gibb.**

Mr. E. A. Turrall has been appointed works manager of the Dunlop Rim and Wheel Co., Ltd., No. 1 Factory, Foleshill, Coventry.

Mr. William Udall, A.M.I.Mech.E., has been appointed chief engineer of the Brightside Foundry and Engineering Co., Ltd. **Mr. A. F. Dixon** will continue to serve the company as consulting engineer.

Mr. L. Copeland Watts has been elected President of the Institution of Heating and Ventilating Engineers.

BUSINESS NOTES.

The Mavitta Drafting Machines Ltd. have now completed their removal to more commodious premises in Highlands Road, Shirley, Birmingham. (Telephone: Solihull 2231-2.)

PRODUCTION OF NEW SYNTHETIC RESINS.

THE Permutit Co., Ltd., has started production this month in their new factory at Pontyclun, near Cardiff, of ion exchange materials of all types, especially the new synthetic resins which were originally developed by The Department of Scientific & Industrial Research. Since then very considerable research work has been carried out and important improvements made by the Permutit Research Laboratories on these materials which are of the greatest interest to industry in general, in view of their remarkable properties. They can be used for the production of distilled water without the necessity for application of heat, for the concentration of dilute chemical solutions for the recovery of traces of precious materials present in large volumes of water which would not be economic to recover by evaporation, and for the purification of many chemical solutions to improve yield of product and quality of product. At the same time these materials can be used for water treatment for the production of soft and non-corrosive water for any requirement.

The remarkable properties of these resins enable a process water to be prepared of any required composition irrespective of the composition of the crude water. These materials are used in chemical factories, power stations, general industry, laundries, etc., and are of the greatest importance as fuel savers, not only from the point of view of the prevention of scale and corrosion in boilers, but also from their properties as concentrators of chemical solutions and removers of dissolved salts without the necessity for distillation.

In their use as water softeners they can also make a valuable contribution towards the conservation of our soap supplies both in the textile industries, laundries, and in the home. As examples of chemical processes to which these materials can be applied outside the field of water treatment we can give the examples:

1. Purification of sugar solutions from dissolved mineral salts.
2. Recovery of copper from cuprammonium waste liquors.
3. Isolation of alkaloids such as nicotine.
4. Catalysis of chemical reactions.
5. Recovery of traces of precious metals from dilute trade wastes.

A further product of the Pontyclun factory is the well known "Permutit" desalting equipment for the production of drinking water from sea water with a very compact equipment yielding six times its own volume of drinking water by purely chemical means without any use of fuel. This was used by the Services during the war for emergency purposes and is now a standardised part of their equipment, as well as on the civilian overseas airlines.

This new factory has been developed in view of the national importance of these materials whose use and application has been increasing throughout the war period. It will enable production to be extended both in the direction of home industry and for export.

The factory has been sited in the development area of South Wales to provide employment of a new type in conformation with the policy of the Board of Trade in diversifying the industries of this part of the country.

FLASH BUTT WELDING OF ALUMINIUM ALLOYS.

SCIAKY Electric Welding Machines Ltd., of Slough, announce the introduction of a flash butt welding machine for aluminium alloy sections. This machine Type F.B.A. depending upon the manner in which it is tooled, is suitable for either straight or mitre joints, and has been developed very largely owing to the great demand for the use of this process in fabricating light alloy assemblies and particularly aluminium window frames, wheel rims, tubes, etc.

This machine which has been developed entirely in Great Britain follows in general the outline of machines of the same type used on mild steel. The welding operation, however, is of novel conception and utilises compressed air incorporating a special "Sciaky" system of variable speed and synchronised flashing and upsetting, individually controlled and adjustable.

A machine of this type suitable for window frame sections and similar section approximating to the same cross sectional area, is rated at 200 kVa, and this type of machine is fully automatic in its welding cycle, and can be used by completely unskilled operators.

A photograph of this machine is unfortunately not available at the moment, but a prototype machine can be seen in operation at Slough.

THE GAUGE AND TOOL EXHIBITION—1948.

The Gauge and Tool Exhibition, 1948, will be held at the New Hall of the Royal Horticultural Society, Elverton Street, Vincent Square, London, S.W.1, from Monday, January 26th to Friday, February 6th, inclusive.

The Exhibition will be opened on Monday, January 26th, at 10 a.m., by the Rt. Hon. Oliver Lyttelton, D.S.O., M.C., M.B., Chairman of Associated Electrical Industries Ltd., and President of the Advertising Association.

Nearly one hundred exhibitors will be showing products such as Gauges and Measuring Equipment; Jigs, Fixtures, and Special Tools; Special Purpose Machines and Equipment; Press Tools; Moulds and Dies; Diamond Tools; Electric and Pneumatic Portable Tools; and a wide range of Engineers' Cutting Tools. Some of the Exhibitors sent us the following information of their Exhibits:—

THE SHEFFIELD TWIST DRILL AND STEEL CO., LTD.

THE Sheffield Twist Drill and Steel Co., Ltd., exhibit a representative range of tools manufactured under the trade mark of "Dormer Brand." The employment of modern methods and up-to-date plant in the manufacture of these tools with rigid inspection, combined with continuous research have enabled them to attain a proud position in the manufacture of accurate reliable Twist Drills, Reamers, End Mills and similar small tools of a consistent high quality.

Dormer Mammoth Twist Drill—12″ diameter, nearly 6′ long.

Normally they carry in stock, well over 3,000 different sizes and varieties of engineers small tools. Limitations of space allow to exhibit but a few of these standard lines. Examination of their catalogue, however, will show the types and ranges of sizes of various tools which are stocked as "Standards."

It will probably be of particular interest to engineers seeking tapping and clearance sizes to know that they normally stock as standard Drills the full range of Metric Size Jobber Drills from ·35 mm. to 13 mm., inclusive, advancing by ·025 mm. up to 1 mm., ·05 mm. up to 5 mm. and ·1 mm. up to 13 mm.

Other tools exhibited of considerable interest is the range of extra long Drills normally carried in stock with both Straight Shanks and Tapered Shanks from sizes 1/16 in. diameter 6 in. long overall up to 1½ in. diameter 24 in. long overall. Special interest may also be aroused by their recently designed high power tooth form which is applied both to Tapered Shank End Mills and Shell End Mills alike.

Exhibits include: Jobbers in Fractional, Metric, Gauge and Letter sizes, H.S. Taper Shank Drills 1/16 in. to 3½ in. H.S. Taper Shank Reamers ¼ in. to 2 in. T Slot and Woodruff Cutters. Centre Drills, Lathe Centres. Hollow Mills. Counterbores.

A. C. WICKMAN LTD.

IN addition to a display covering the recent valuable developments in the application of their Wimet tool metal, A. C. Wickman Ltd. are exhibiting a revolutionary inspection instrument, the Cornelius Electronic Comparator, for which they are sole world agents. The aim in developing this comparator is the production of a standard electronic instrument capable of carrying out more efficiently, more rapidly and non-destructively all the usual inspection tests required in modern production engineering; making possible, by means of a single basic instrument to which simple probes or adaptors may be connected, the application of positive tests to complete batches of components and material where previously only small percentage tests of a destructive or complex nature could be applied.

During the past year the instrument has been applied to a number of tests under normal working conditions in a wide field of indus-

GOOD TEMPERED FOR SERVICE

As springs must be. But whereas human response varies in every individual, the millionth spring of an order must have exactly the same character as the first approved sample. Whatever size or shape is needed, we feel confident that we can help you.

THE TEMPERED SPRING CO. LTD.
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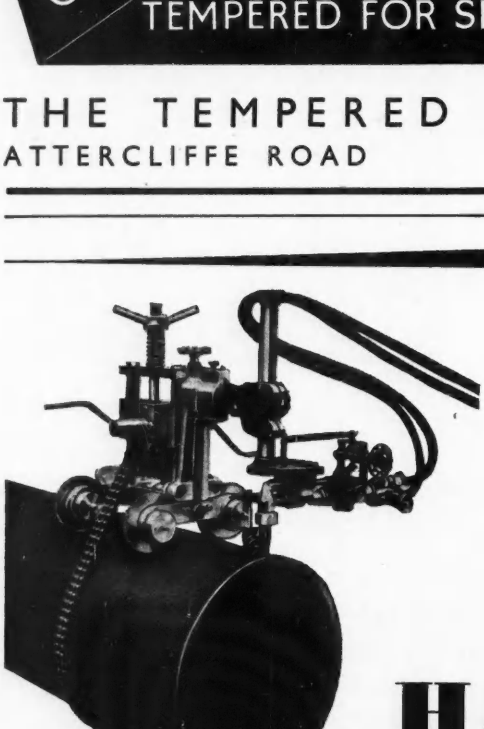

Pipe Dream!

The Hancock chain drive PIPE CUTTING machine will CUT pipes of any diameter from 4 inches upwards at a right angle or a bevel up to 45°.

The four wheel hand-driven carriage carrying the cutting burner is held firmly against the face of the pipe by an endless length of chain. It is simple to operate, yet allows pipes to be CUT with speed and accuracy.

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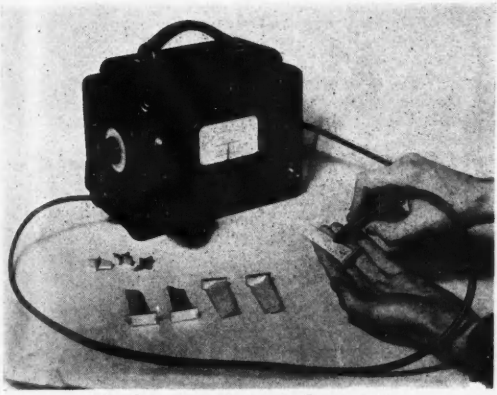


The Cornelius Electronic Comparator.

tries, solving many problems in the inspection of parts requiring an accurate yet non-destructive examination for defects on or below the surface. The success of these applications suggests that the instrument has now reached a stage in its development when it can become more generally acceptable as a practical inspection medium. Even so, the great wealth of possible applications of the instrument has hardly been touched upon; neither in overcoming inspection problems to which there has never before been a satisfactory solution, nor in replacing established methods by a more rapid and reliable technique, has the instrument been fully exploited.

Six sets, all basically the same but connected to different adaptors, are being shown. Each of these comparators demonstrates a different field of application, and the simplicity and speed of operation combined with the extreme accuracy obtained in both detection and measurement in every case give a sound indication of the headway that has been made in the development of the instrument.

The Cornelius Electronic Comparator is a portable unit no larger than a table-model radio set, plugged into the normal 230 volt 50 cycle supply and having a power input of 30 watts. Its operation is based on the principle that the structural formation of all substances is always basically the same; that each similar atom and molecule must respond to a definite electronic disturbance in precisely the same way according to its structural value. Two identical test subjects placed in the electronic field of the instrument will therefore modulate the frequency of that field in exactly the same way, producing identical indications on the instrument meter.

It is therefore possible to compare a series of test subjects precisely with a standard test-piece of known value, since any defect or divergence from the standard will cause a variation between the meter reading obtained with the standard test-piece and that obtained with the test subjects. By means of two controls on the instrument the variation in the frequency of output caused by the introduction of the test-piece into the field can be annulled and the frequency brought back to basic, and it is therefore possible to zero-set the instrument meter to any test-piece placed in the adaptor.

The sensitivity of the instrument is such that in testing bar stock, for example, the inclusion of 1 per cent nickel in a bar is sufficient to deflect the meter needle right out of indicator range when the instrument is zero-set by a bar containing no nickel.

Applications of the instrument to production engineering inspection can be classified in six groups :—

Material and component inspection for chemical composition, hardness, and for cracks and flaws of all types on or below the surface. Dimensional comparison, with micro-inch sensitivity. Plating and coating inspection, including verification of the adhesion of plating or under-coating. Surface finish comparison. Stress-strain analysis. Hardness testing, particularly of parts with highly finished surfaces and where the operating area is restricted.

The display of Wimet on the stand includes many developments which have come to the fore during the past year, and it is interesting to note the wide variety of tools representative of applications in the sheet-metal and other industries where increasing use is being made of this brand of carbide for press tools, such as segmental dies for blanking and piercing, forming dies, slitting discs for strip steel, extruding and cold heading dies for bolt manufacture, and hot extrusion dies for brass, copper and other non-ferrous materials.

The demand for these tools has greatly increased of late due to their long life expectancy, which has proved, from reports received from users, to be as much as 400 times as great as that of their steel counterparts in the case of segmental dies, more than 50 times as great for heading dies, and more than 35 times as great in the case of slitting disks for high-carbon steel razor-blade strip.

Also on show is the "Multimill" milling cutter with solid inserted Wimet blades, designed on principles formulated and proved in the manufacture of Wimet single point turning tools with which most production engineers are familiar. Since its introduction almost a year ago, this cutter, which in standard form can be adapted for milling materials as diverse as light alloys and steel, has been proving its capabilities in service. Used in a heavy motor vehicle works, for machining 8 in. × 36 in. cylinder blocks, the cutter has required relapping only after 45 blocks have been machined. On test, the cutter has given metal removal rates of 2·12 cu. ins./per h.p./per minute for 180 Brinell cast iron and ·98 cu. ins./per h.p./per minute for ·5 carbon steel.

New production methods at the Wimet Works are reflected in the lowered prices for the range of plain and screw plug gauges exhibited, and on a price for price basis their comparison with steel gauges is very favourable. The extreme hardness of Wimet renders it capable of taking an average surface finish between zero and 0·4 micro-inches, and its wear resistant properties ensure retention of this finish over long periods of work, giving a "life" many times that of any other material. The range of screw gauges provides a complete line in Whitworth, Pipe and Metric forms.

E. H. JONES (MACHINE TOOLS) LTD.

ALTHOUGH not members of the Gauge & Tool Makers' Association, Messrs. E. H. Jones (Machine Tools) Ltd., of Edgware Road, The Hyde, London, N.W.9, will be represented at this forthcoming exhibition by Sigma Instrument Co., Ltd., of Letchworth, and Offen & Co., Ltd., of King's Mill Lane, South Nutfield, Surrey.

These Companies are combining stands Nos. 16 and 17 which will be organized jointly with E. H. Jones (Machine Tools) Ltd. By uniting the displays of Sigma and Offen, this company is presenting a most comprehensive display of measuring equipment ranging from micrometer gauges, micro boring bars and heads, to mechanical, optical and electrical comparators and the fully automatic multi-inspection machines. Of the latter, the model on display will be the very latest development in a system which is rapidly being accepted throughout Great Britain and extending its hold on the more advanced manufacturing countries of the world.

NEW EQUIPMENT.

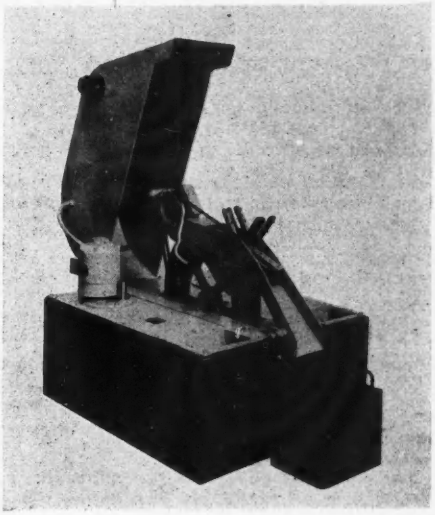
PHILIPS NEW MAGNETIC CLARIFIER FOR IMPROVED SURFACE FINISHING.

USERS of grinding, honing or lapping machines, or any machine producing fine swarf are fully aware that the highest class of surface finish of which such machines are capable cannot possibly be obtained so long as grinding swarf and broken abrasive grit is allowed to circulate in the coolant.

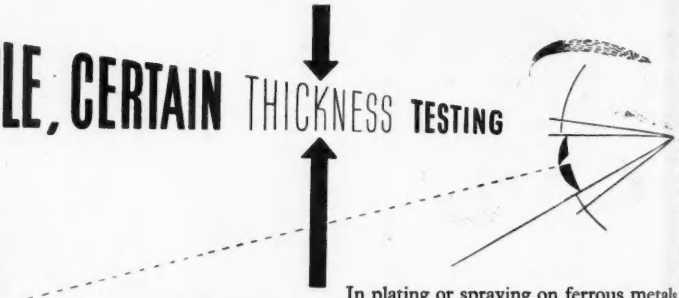
The majority of these machines are, unfortunately, undertanked. Further, these tanks are not cleaned sufficiently nor often enough. To obtain a high class of surface finish, therefore, the machine must be equipped with some additional form of coolant cleaning device which will automatically and continuously remove the fine ferrous swarf and broken abrasive suspended in the coolant.

By acquiring the exclusive manufacturing and marketing rights of the Scrivener Clarifier, Philips Industrial (Philips Electrical Ltd.) have included in their well-known range of magnetic filters, a model of far greater capacity for bulk sludge removal than has hitherto been available, and one which is certain to solve the problem of heavily contaminated coolant, especially where ferrous swarf is concerned.

The principle of operation of the Clarifier is simple and efficient. It consists of a comparatively small distributor tank to which the coolant is fed through a restricted channel past a rotating disk which carries a number of very powerful magnets. This aluminium disk revolves slowly, and any ferrous matter and grit contained in the used coolant as it passes through this restricted channel is collected by the magnets and brought round by the revolution of the disk (which works in an upright position) to where wiper arms remove the ferrous and grit particles and deposit them in a separate discharge channel. This channel transfers the contamination to a bucket or other receptacle placed to receive the sludge. The



NOW - SIMPLE, CERTAIN THICKNESS TESTING



In plating or spraying on ferrous metals thickness is the test of quality. And thickness is now so easily measured that a careful check can always be maintained.

The Marconi THICKNESS METER operates on non-magnetic coatings; it reads directly in terms of thickness and does not damage the surface in any way. Tests discriminating to 0·0001 can be made in a few seconds on edges, flat or curved faces, the maximum range being 0·01.

As an inspection tool or merely as a comparator, this mains-operated instrument, type TF 884, is completely reliable. The cost is moderate and details can be obtained upon request.

THE MARCONI THICKNESS METER

MARCONI INSTRUMENTS LTD

ST. ALBANS, HERTS. **Telephone: St. Albans 6161/5**

Northern Office:	30 ALBION STREET, HULL.	Hull 16144
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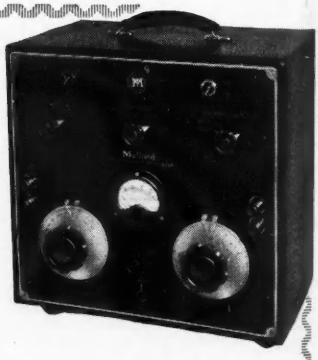
MULLARD BEAT FREQUENCY OSCILLATOR TYPE E.810

Versatile A. F. Generator



The chief features of this compact oscillator are its wide frequency range, constant output and low harmonic distortion. Arrangements have also been made whereby the amplifier may be operated separately.

It is extremely useful for studying the audio frequency characteristics of transformers, amplifiers, transmission networks and allied radio and telecommunication equipment.

There are many other uses for this versatile instrument which should form part of the test equipment in all electrical development and research laboratories.

Specification

Mains Input	100-150 and 200-250 V. 50 c/s.
Frequency Range	15 c/s.-21 Kc/s.
Percentage Total Harmonic Distortion (Max. Output)	1%
Percentage Hum Level (Max. Output)	0.1%
Power Output	4 watts
Output Impedances	2,500 : 600 and 15 ohms.
Output Constant within 1 dB over the entire Frequency Range.	

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cleaned coolant is then pumped back into the machine. A small electric motor serves to drive the disk and wiper arms.

The action of the Philips Magnetic Clarifier is entirely automatic and it requires no attention or supervision.

HEY 10 INCH GEAR TOOTH ROUNDING AND CHAMFERING MACHINE.

THE new 10 in. Gear Tooth Rounding and Chamfering Machine shown in Fig. 1 is an entirely new post-war development. Its productive capacity is greatly in excess of the pre-war 8 in. capacity machine, and increases of output of more than 100 per cent have been achieved.

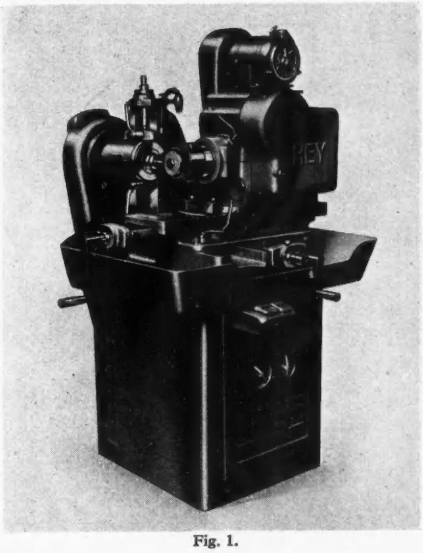

Fig. 1.

Gears up to a maximum diameter of 10 in. are accommodated and with a maximum of 160 teeth.

The machine is provided with screw operated slide adjustments in three directions, and the work head can be swivelled through 40 deg. The latter has feed rates ranging from 16 to 90 teeth per minute from a self-contained motor through five-stepped cones and vee ropes.

The shape produced on the ends of gear teeth is controlled by an interchangeable cam mounted at the rear of the work spindle, the standard shapes are shown in Fig. 2.

For quantity production the work head can be arranged to operate on a fully automatic cycle when the start button is pressed, giving one or more roughing cuts followed by a finishing cut and stopping the machine in the loading position.

The cutter spindle is carried on double row angular contact ball bearings, and is driven through vee ropes from a motor in the base of the machine, speeds ranging from 1000 to 3000 r.p.m.

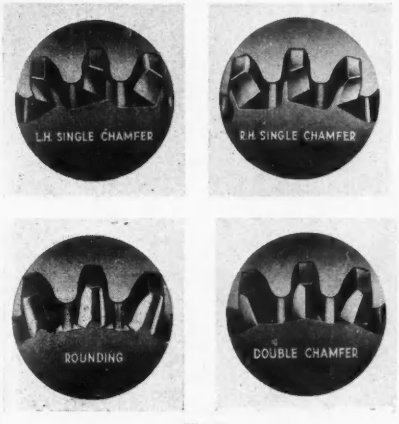

Fig. 2.

The horizontal cross slides are provided with quick acting acme screws and built-in micrometer dead stops. These permit the work to be rapidly withdrawn for loading and unloading, and returned to the correct position for the operation. Locking levers are provided to all slides.

All the electrical control gear is mounted on a hinged panel on the front of the base, and the machine is complete with a gear type coolant pump and fittings.

H·G·SMITH
(STEEL FABRICATIONS) LTD.
The ATOMIC
all Steel
BARROW
WELDED CHASSIS
SEPARATE UNIT
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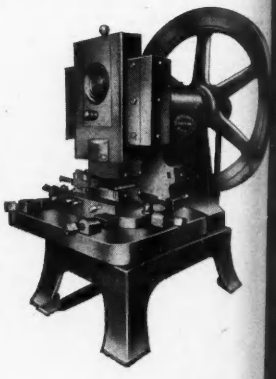

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